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Prepared by:
Nigel Keeley, Chris Cornelisen, Ben Knight, Barrie Forrest and David Taylor
Cawthron Institute

For:
Waikato Regional Council
Private Bag 3038
Waikato Mail Centre
HAMILTON 3240

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Dr. Dominique Noiton
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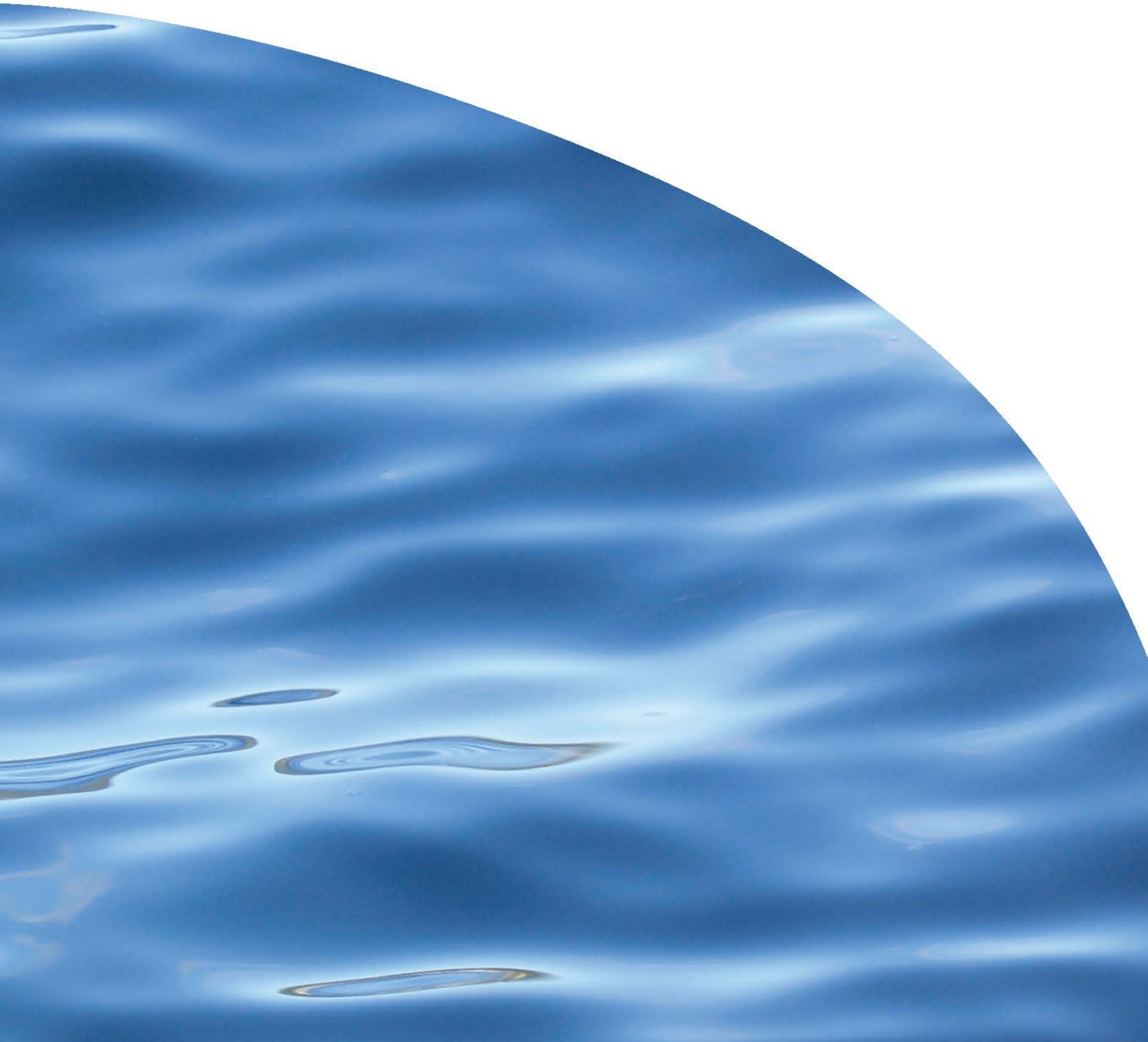
MONITORING FRAMEWORK FOR THE WAIKATO COASTAL MARINE AREA: REPORT 3‑SEABED AND WATER COLUMN MONITORING AND STANDARDS



MONITORING FRAMEWORK FOR THE WAIKATO COASTAL MARINE AREA: REPORT 3‑SEABED AND WATER COLUMN MONITORING AND STANDARDS

NIGEL KEELEY, CHRIS CORNELISEN, BEN KNIGHT, BARRIE FORREST, DAVID TAYLOR

Prepared for Waikato Regional Council

CAWTHRON INSTITUTE
98 Halifax Street East, Nelson 7010 | Private Bag 2, Nelson 7042 | New Zealand
Ph. +64 3 548 2319 | Fax. +64 3 546 9464
www.cawthron.org.nz

REVIEWED BY:
Grant Hopkins

APPROVED FOR RELEASE BY:
Natasha Berkett

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EXECUTIVE SUMMARY

Waikato Regional Council (WRC) has recognised the need to rationalise and improve environmental monitoring for the Waikato coastal marine area (CMA). As part of WRC's steps towards meeting this need, Cawthron Institute (Cawthron) has developed a framework that integrates consent-related and wider state of the environment (SOE) monitoring. Using aquaculture as the first case study for the framework, a three-report series has been produced to present the framework and develop ecological monitoring requirements and standards for aquaculture in the CMA. The three reports are as follows:

Report 1: Monitoring framework: Presents the rationale and key elements of a regional monitoring framework that integrates monitoring associated with consented activities and wider State of the Environment (SOE) monitoring (Forrest & Cornelisen 2015).

Report 2: Regional guidance on priority issues and monitoring: Covers the ecological effects of aquaculture in the Waikato CMA and identifies the priority issues that need to be addressed through industry best practice and reporting, and / or through monitoring of effects (Forrest *et al.* 2015).

Report 3: Monitoring methodologies and standards: Recommends methodologies and standards for monitoring the seabed, water column and the wider environment in relation to the potential effects of aquaculture.

This document is the third report in this series. Besides the recommendations covering monitoring methodologies and standards, it also provides recommendations on ways to improve Council-led SOE monitoring and better capture cumulative environmental change, including benefits from integrating consent-based and SOE monitoring programmes.

A standardised approach to consent-based monitoring is proposed for the Waikato CMA that builds on the success of protocols and standards developed for monitoring and managing salmon farm consents in the Marlborough Sounds. The fundamentals of seabed monitoring is based on multi-variable (integrated) indicators of enrichment and the setting of trigger thresholds (or limits) for these indicators at pre-specified distances from the farms. Key enrichment indicators to monitor include organic matter content, concentrations of sulphides and redox potential, along with statistics that describe the macrofauna communities within the sediments (*e.g*. organism abundance and diversity). These indicators can be used in isolation, or combined into a single, integrated measure of Enrichment Stage (ES) that ranges from pristine (1) to heavily impacted (7) conditions.

Data from existing datasets for the Firth of Thames and around the Coromandel were used to calculate preliminary ES scores and test whether relationships between variables for determining ES may need to be tailored to the region. Analyses of existing data demonstrate a wide range of seabed conditions across the areas sampled. Additional work is required to properly establish reference conditions and relationships among key indicators used in calculating ES.

Protocols and indicative environmental quality standards (EQS) for the two main categories of aquaculture are proposed for non-feed-added aquaculture such as farming of mussels and for feed-added aquaculture such as finfish farms. A tiered approach is recommended for determining monitoring requirements, whereby different levels are required according to the type of aquaculture and the history of the farm in terms of management and environmental performance. We provide decision trees to determine the level of monitoring required. For example, monitoring for feed-added aquaculture can range from rapid qualitative monitoring (Level 1) to monitoring a full suite of benthic indicators and ES (Level 3).

The preliminary EQS are similar across different forms of aquaculture. The standards assume a moderate-to-highly enriched state is permitted beneath a farm and anywhere within the consented area. A moderate-to-highly enriched seabed is denoted by ES 4 with corresponding specific thresholds given for specific indicators such as number of taxa and total free sulphides. Preliminary standards are recommended using the basic indicator variables.

A fundamental gap in the information collected to date is a description of how the sediments respond to severe enrichment in different locations. New site-specific information will provide added confidence in the evaluation of indicators and for setting environmental standards for ongoing management. The data obtained during the implementation phase of the protocol can be used to test the applicability of existing ES to environmental variable relationships and to derive site / region specific ES where necessary. It is also important to determine what constitutes a ‘pristine’ soft-sediment habitat in the region. This information is important for evaluating levels of effects and future changes, as well as for setting reference conditions.

In order to determine what should be recommended as part of water column monitoring, available data and knowledge from aquaculture monitoring and research programmes in the Waikato CMA were reviewed. To date, monitoring of water column effects from aquaculture in the Waikato CMA has focused on the effects of mussel farming in the Wilson Bay Marine Farming Zone on the depletion of phytoplankton and the composition of plankton communities. More than eight years of monitoring involving intensive plankton surveys has not detected significant effects of mussel farms on plankton communities. Previous studies also demonstrate that the inner Hauraki Gulf, including the Firth of Thames, displays variability in water column conditions that limit the ability to measure changes attributable to existing aquaculture in the region. These outcomes indicate that water column monitoring for individual aquaculture consents needs to be integrated with other consent and SOE monitoring programmes in order to adequately capture reference conditions and wider, cumulative environmental changes that may be occurring.

We recommend that water column monitoring required for consents focuses on the local scale where effects are measureable and can be attributable to a farm’s activities. In the case of non-feed-added aquaculture, it is recommended that consent monitoring of water column effects be required only in certain situations; for instance, when a significantly-sized mussel farm is being developed in an undeveloped area where no data or knowledge on water column conditions exist. The recommended parameters for water column monitoring required as part of consent conditions for non-feed-added aquaculture include chlorophyll-*a*, a proxy for phytoplankton.

We recommend that water column monitoring be required for all feed-added aquaculture consents. Consent monitoring should focus on the local-scale water quality issues that are directly linked to farm attributes that can be managed, such as stocking densities and feed inputs. Key parameters linked to these attributes include dissolved oxygen (DO) and concentrations of dissolved inorganic nitrogen (especially ammonia). Standards for DO should be set at a level that avoids reductions that are potentially harmful to marine biota. An additional standard can be set to avoid toxicity effects (as in the case of ammonia) and nutrient concentrations outside the confines of natural variation beyond the local farm scale.

The primary information gap for water column monitoring is understanding existing conditions, so that any future monitoring can be used to effectively manage aquaculture consents. These data are also required to refine and implement standards, which may need to vary across different regions of the CMA due to a location's natural characteristics and gradients in existing conditions.

There is an opportunity to greatly strengthen Council-led SOE monitoring and the usefulness of knowledge it provides by integrating consent monitoring for aquaculture (described in the earlier sections) with Council SOE monitoring efforts. Several factors need to be considered to broaden and improve an SOE monitoring programme that aligns with consent monitoring, including a framework for integration, selection of appropriate indicators, and a sampling design that captures the appropriate spatial and temporal scales.

As in the case for consent monitoring, we recommend an indicator approach to SOE monitoring in the Waikato CMA that enables assessment of the overall health and condition of the CMA and tracks progress in relation to overarching environmental management and policy goals. Monitoring of indicators must be carried out over the long term and sufficiently integrated across ecosystem components in order to contextualise changes resulting from anthropogenic activities and natural processes; this is also required for assessing cumulative effects.

In order to facilitate integration of SOE and consent monitoring, we recommend using the ES approach for monitoring seabed conditions in soft sediment habitats. For the purpose of SOE monitoring, the number of parameters measured for determining ES may vary compared to requirements for consent monitoring for aquaculture, but could contain enough common parameters to provide useful comparisons and overlay of results. For the water column, we recommend measuring a full suite of standard indicators and trialling various trophic indices that can be interpreted alongside ES scores.

In designing the SOE monitoring programme, we recommend using a staged approach whereby the SOE programme focuses initially on the collection of quality data at a low number of sentinel sites that coincide with the location of moored sensors (*e.g*. the buoy Wai-Q-Tahi in the Firth of Thames). Measuring benthic indicators for calculating ES at the same locations will also enable review of integrated metrics that combine benthic and water column indicators. Following a review of results, the appropriate suite of indicators and integrated metric, and the frequency they need to be measured, would be selected and then applied wider across the CMA as required and feasible.

Three overarching steps to successfully integrating consent-based and SOE monitoring include: (1) developing an effective integrated monitoring design, (2) determining how best to cover the costs associated with carrying out wider environmental monitoring and also integrating and managing datasets held by different users, and (3) effective governance and oversight. In terms of the second and third steps, it is envisioned that WRC develops a system for supporting an integrated monitoring programme that is supported through a variety of funding sources (industry, regional and central government, sponsorship), and that the governance of the programme includes participation by industry and other end users of the data and information generated by the programme. This could be accomplished by establishing a coastal monitoring advisory panel.

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1. INTRODUCTION

Waikato Regional Council (WRC) has recognised the need to rationalise and improve environmental monitoring for the Waikato coastal marine area (CMA) (Figure 1). As part of WRC's steps towards meeting this need, Cawthron Institute (Cawthron) has developed a framework that integrates consent-related and wider state of the environment (SOE) monitoring. Using aquaculture as the first case study for the framework, a three-report series has been produced to present the framework and develop ecological monitoring requirements and standards for aquaculture in the CMA. The three reports are as follows:

- **Report 1: Monitoring framework:** Presents the rationale and key elements of a regional monitoring framework (Figure 2) that integrates monitoring associated with consented activities and wider state of the environment (SOE) monitoring (Forrest & Cornelisen 2015)
- **Report 2: Regional guidance on priority issues and monitoring:** Covers the ecological effects of aquaculture in the Waikato CMA and identifies the priority issues that need to be addressed either through industry best practice and reporting, or through monitoring of effects and management of consented activities (Forrest *et al.* 2015)
- **Report 3: Seabed and water-column monitoring and standards:** Recommends methodologies and standards for monitoring the seabed, water column and the wider environment in relation to the potential effects of aquaculture.

This report is Report 3 in the series. It focuses on monitoring protocols and standards for managing aquaculture consents in response to environmental effects that are measureable and directly attributable to the activity (*i.e.* seabed and water-column effects within the vicinity of farms). This represents Step 4 in the proposed monitoring framework for the Waikato CMA (see Figure 2). The report also reviews approaches to monitoring wider ecosystem change through use of multi-trophic indicators. Gaps in coastal environmental data and information have been identified in order to effectively implement monitoring standards for consents as well as wider SOE monitoring. Recommendations have also been made for implementing indicator(s), for long-term monitoring to assess change, in accordance to WRC plan objectives. Opportunities and examples of integrating consent-related and SOE monitoring in the Waikato CMA (Step 3 in the framework) are also provided.

Effects beyond the seabed and water column processes described in this report include those associated with marine mammals, increased risk of invasive species or the use of additives (*e.g.* trace metals, therapeutants, antibiotics). These issues are best addressed through reporting and adoption of best management practices (BMPs) aimed at reducing impacts, irrespective of actual or potential risk (see Report 2 for further discussion). As defined in Report 1, monitoring is an activity that can be conducted in a systematic manner and planned in advance, whereas reporting involves collection and recording of *ad hoc* data, which may be periodically collated by a consent holder and reported to the regulating agency.

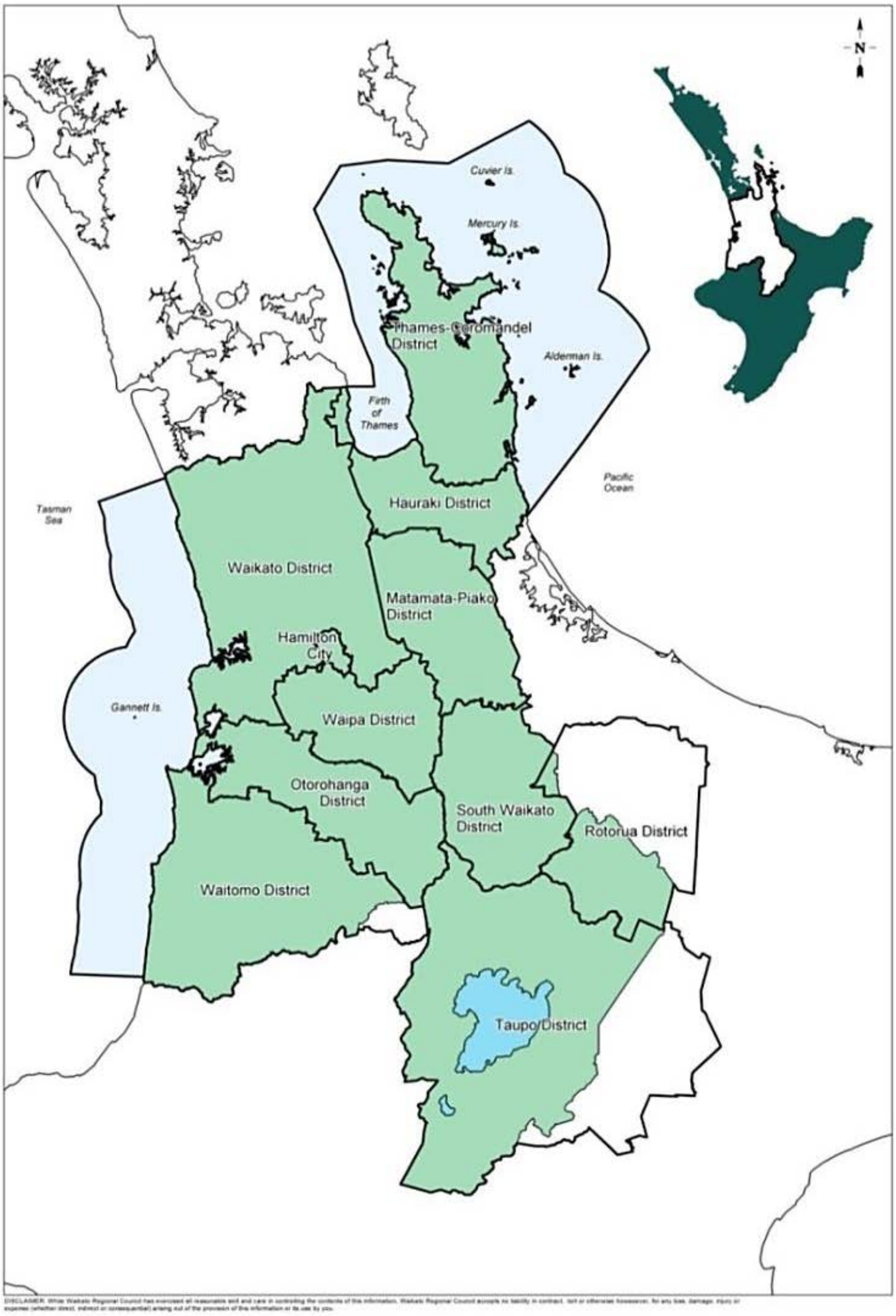

Figure 1. The Waikato coastal marine area (CMA; blue shading) includes west coast harbours , the Firth of Thames and south-eastern Hauraki Gulf, as well as the coastline and many estuaries along the eastern side of Coromandel Peninsula. Source: Waikato Regional Council.

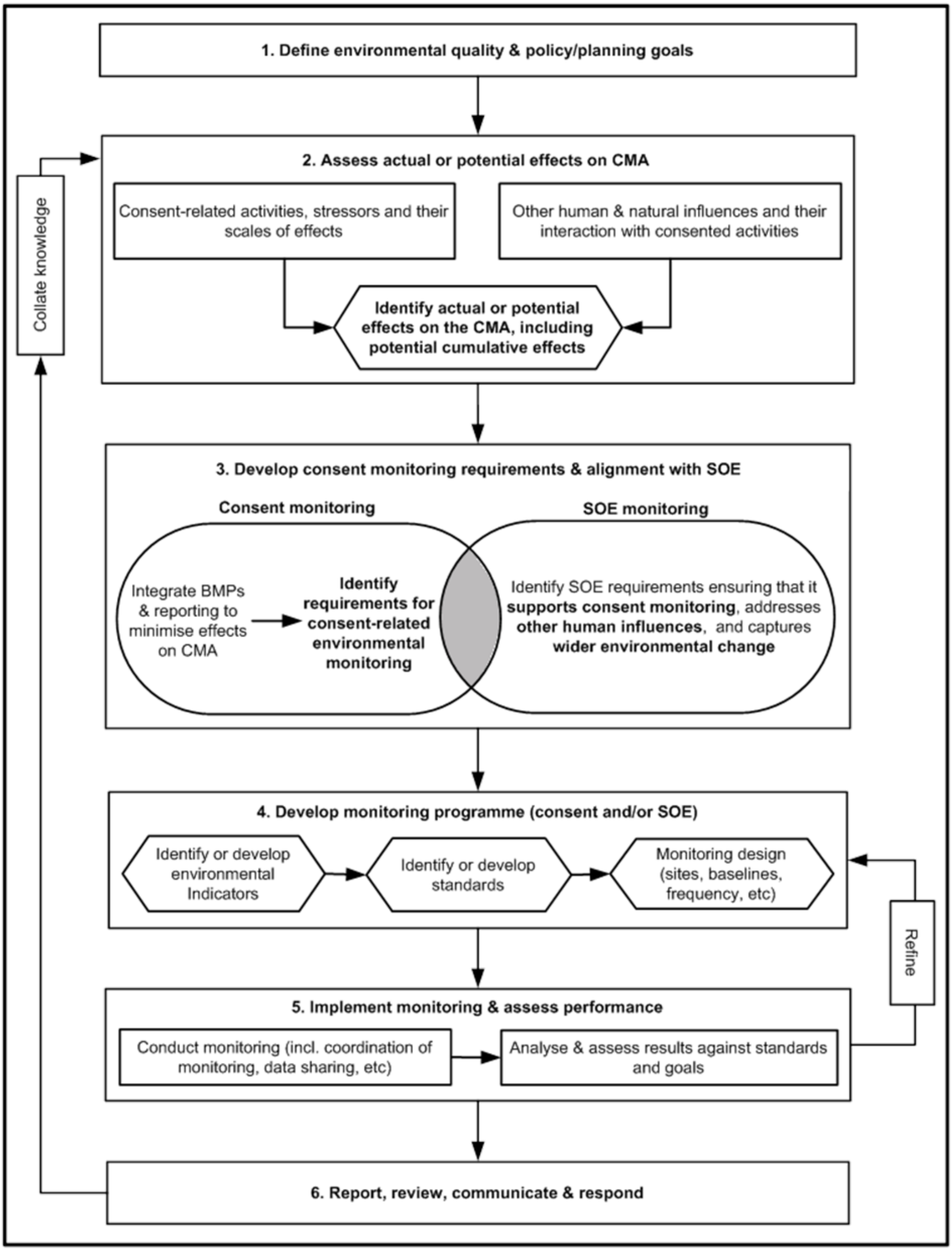

Figure 2. Regional monitoring framework described in Report 1. This report focuses on Step 4, and also provides recommendations around integrating consent-based and state of the environment (SOE) monitoring programmes (Step 3).

1.1. Report aim and objectives

The primary aim of this report is to guide WRC in the implementation of monitoring protocols and environmental quality standards (EQS) for managing aquaculture consents in the region. Wider monitoring efforts and monitoring change relative to EQS will assist in understanding the role of different activities in driving wider environmental change (*i.e.* cumulative effects) and also gauging overall water quality and ecosystem health for SOE reporting.

The four main sections of the report are dedicated to:

1. presenting monitoring methods and standards for managing aquaculture consents based on seabed (benthic) effects (Section 2).
2. reviewing baseline water column conditions and assessing effects of aquaculture on the water column and ways to monitor these effects (Section 3).
3. recommending approaches for wider SOE monitoring in the Waikato CMA (Section 4).
4. identifying opportunities to integrate consent-related aquaculture monitoring with wider SOE monitoring (Section 5).

Report objectives according to the sections in which they are addressed include the following:

Section 2: Monitoring seabed effects

- propose an overall approach to aquaculture monitoring in the Waikato CMA based on multiple indicators of seabed effects and the use of an integrated measure of enrichment stage (ES)
- review existing data on seabed characteristics in the Waikato CMA and describe baseline conditions (including estimates of ES) and the likely extent of seabed effects from different forms of aquaculture
- provide seabed monitoring protocols and standards for aquaculture based on protocols developed in other regions (Marlborough Sounds) for application in the Waikato CMA.

Section 3: Monitoring water-column effects

- review existing data on water column characteristics and describe baseline conditions and the likely extent of water-column effects from aquaculture, with a detailed example based on finfish farms and considering local to regional (*i.e.* cumulative) effects
- review existing approaches to monitoring water-column effects associated with aquaculture; where possible make recommendations on implementing consent-related water-column monitoring in accordance with standards.

Section 4: Addressing broad-scale effects through SOE monitoring

- review and recommend most suitable indicator candidates for addressing gaps in wider SOE monitoring in the Waikato CMA; identify data needs for instituting indicator(s) for long-term monitoring and standards for assessing change in accordance to WRC plan objectives.

Section 5: Integrating consent-related and SOE monitoring

- describe how consent-related aquaculture monitoring can be integrated with wider SOE monitoring for achieving a more efficient and informative outcome for the aquaculture industry and the region.

1.2. Overview of aquaculture in the Waikato CMA

Aquaculture within the Waikato CMA is currently dominated by 'longline' culture of green-lipped (or Greenshell™) mussels (*Perna canaliculus*) within the Wilson Bay Marine Farming Zone (WBMFZ), and smaller farms around the Coromandel Peninsula and along the West Coast (Figure 3). The WBMFZ is the dominant area of mussel aquaculture in a location ranging from 15–26 m in depth that overlies muddy sediments. The WBMFZ is set up in two separate parts, having a collective farmable space (*i.e.* excluding space between individual farm blocks) of 1,210 ha (Figure 4). Area C of the WBMFZ consists of 90 ha that has been allocated for feed-added (*i.e.* finfish) aquaculture.

The Coromandel Marine Farming Zone (CMFZ) is an area of 300 ha situated in the south-eastern Hauraki Gulf, which is designated for feed-added aquaculture (Figure 3). This zone lies in about 35 m of water and overlies soft sandy-mud sediments (Grange *et al.* 2011). Further details on marine farming zones in the Waikato CMA are provided in Report 2.

Outside of Wilson Bay, a total of *c*. 300 ha of space along the west coast of Coromandel Peninsula is presently allocated for aquaculture, mostly in Coromandel and Manaia harbours (Figure 3, left side). This includes smaller sites for mussel culture, 70 ha for intertidal Pacific oyster (*Crassostrea gigas*) cultivation on wooden racks in the intertidal zone and some mussel spat catching. Some of the mussel farms have recently been extended (Taylor *et al.* 2012).

Small mussel and oyster farms are also located within harbours of the eastern Coromandel Peninsula, including Whangapoua and Whitianga harbours, and Port Charles and Kennedy Bay (Figure 3, left side, circled). Very little aquaculture has been developed along the west coast of the Waikato region; one mussel and spat catching farm is consented in Aotea Harbour and one oyster farm in the adjacent Kawhia Harbour (Figure 3, right side, circled). In addition to the areas currently farmed, WRC has received consent applications that include extensions to existing mussel farms (Taylor *et al.* 2012) and mussel spat catching areas, and there is the possibility that some mussel spat-catching sites will be converted to on-growing of product.

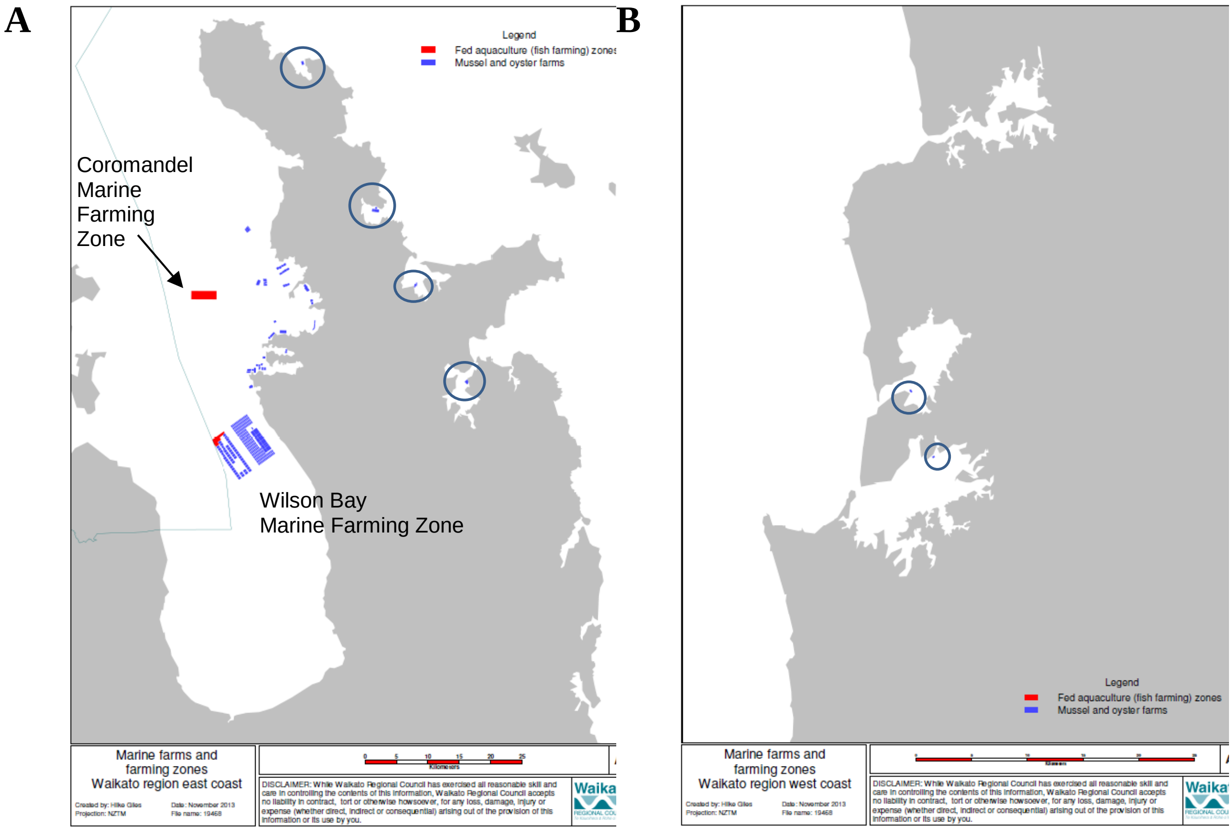

Figure 3. Existing mussel and oyster farms (blue) and feed-added aquaculture zones (red) in the eastern (A) and west coast (B) Waikato Coastal Marine Areas. A close up of the Wilson Bay marine farming zone is shown in Figure 4. Source: Waikato Regional Council.

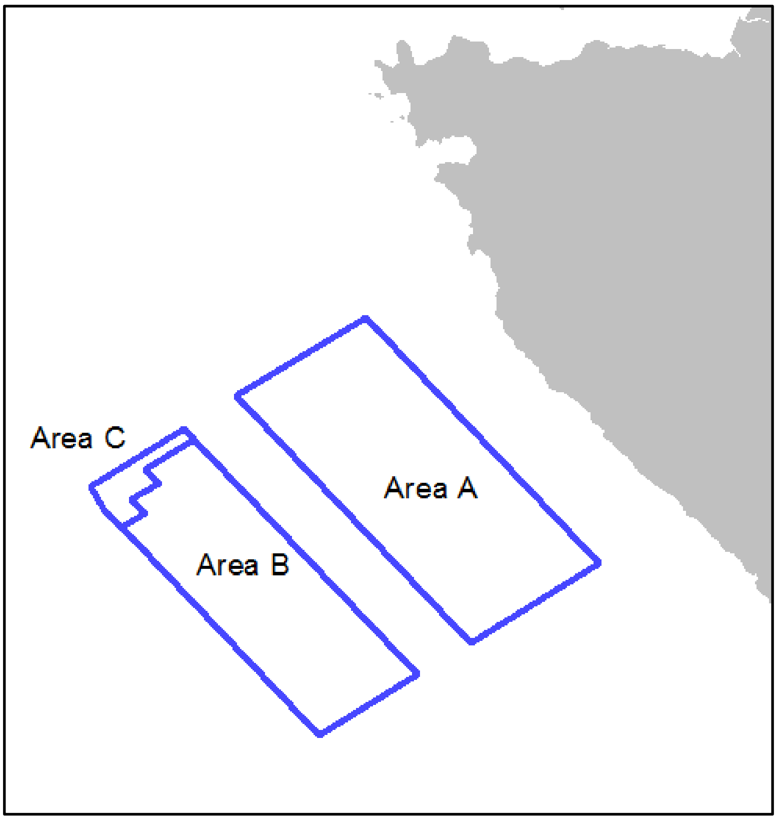

Figure 4. Wilson Bay Marine Farming Zone showing Areas A, B and C. Note that the area shown as Area A includes 220 ha of mussel farming space that does not officially form part of Area A. Area C is designated for future finfish (feed-added) aquaculture. Source: Waikato Regional Council.

2. MONITORING SEABED EFFECTS

Seabed effects associated with the dominant methods of aquaculture in New Zealand (long-line culture of mussels and salmon pens) are generally well understood and documented in the regions they occur (see Report 2). The focus of aquaculture monitoring and research on seabed effects in New Zealand is typical of the situation worldwide. Such effects are relatively easy to measure at the local-scale and the species composition of organisms inhabiting the seabed and within the sediments is considered a very good time-integrated indication of recent stressors; the cause-effect is relatively easy to determine. Sampling and analytical methods are also well developed, and it is therefore relatively straightforward to interpret results in the context of comparable studies.

In the following sections we describe an integrated, multi-indicator approach focusing on seabed enrichment that has been developed and implemented in other New Zealand regions to monitor and manage aquaculture activities. We then outline how this same approach can be applied in the Waikato CMA to monitor seabed effects in accordance with EQS for managing consents across the range of potential aquaculture activities. As part of the process of developing appropriate EQS for the region, we first describe the baseline conditions in the Waikato marine farming zones described in Section 1.2 using data provided by WRC. This baseline information also provides an indication of the likely future conditions that may arise in response to different types of aquaculture, which in turn is required to set EQS for managing aquaculture activities.

The approach and protocols outlined in this section focus on localised seabed effects that are attributable to individual aquaculture farms and can be used to manage individual consents. However, there is also the potential for far-field / wider-ecosystem effects on the seabed, particularly in cases where multiple farms occur within the footprint of land-sourced inputs of sediments and nutrients. These wider environmental effects are best addressed through aligned SOE monitoring, which is described in more detail in Section 4. Linking consent-related and SOE monitoring as described in Section 5 will increase efficiency and cost effectiveness for both forms of monitoring.

2.1. Proposed approach to seabed monitoring

All forms of aquaculture in the marine environment, ranging from oyster and shellfish culture to finfish farms, result in ecological effects to the underlying seabed. Seabed changes from aquaculture are commonly associated with organic enrichment associated with deposition of faecal wastes and other biological material that drops off from farm structures such as biofouling organisms (see Report 2 for further discussion). Despite differences in the nature and extent of effects between different types of aquaculture, a standardised approach across the industry to consent-based monitoring is proposed for the Waikato CMA that builds on the success of protocols and standards developed for monitoring and managing salmon farm consents in the Marlborough Sounds.

The fundamentals of fish farm monitoring in the Marlborough Sounds, and most other finfish-farming regions worldwide (*e.g.*, Wilson *et al.* 2009), are based on multi-variable (integrated) indicators of enrichment and the setting of trigger thresholds (or limits) for these indicators at pre-specified distances from the farms. Although the methods have been used primarily to manage finfish farms, the approach is transferable to other forms of aquaculture. In the following sections we identify the key variables to monitor, and describe how multiple variables can be combined into a single, integrated measure of enrichment stage (ES). Environmental quality standards later recommended in Section 2.3.2 are based on these variables and ES.

2.1.1. Indicators of seabed enrichment

Given the range of enrichment-indicating variables that can be measured, there is inevitably a decision to be made regarding which ones to measure for consent monitoring purposes. Some important factors to consider are: convention and history of use, ease of measurement, cost, and most importantly, robustness, reliability and relevance. Individual environmental variables routinely sampled around mussel and finfish farms in the Marlborough Sounds include:

- macrofauna (identified to lowest practical taxonomic level)
- sediment organic matter content (%OM)
- total free sulphides (TFS)
- redox potential (redox)

Analyses of data on organisms inhabiting the sediments (macrofauna/infauna) provide further useful biological statistics that describe the state of macrofauna populations. These include:

- simple metrics such as: total abundance (N), number of taxa (species richness, S)
- numerically derived diversity metrics: Shannon diversity (H'), Margalef's richness (d), Pielou's evenness (*J'*)
- a wide range of possible biotic indices[1], *e.g.* AMBI (Borja *et al.* 2000), M-AMBI (Muxika *et al.* 2007), BENTIX (Simboura & Zenetos 2002), and BQI (Rosenberg *et al.* 2004).

In a meta-analysis of 12 years' worth of data from beneath salmon farms in the Marlborough Sounds, Keeley *et al.* (2012a) compared the full range of the above metrics for the purpose of reliably discerning all stages across the enrichment

[1] AMBI = AZTI marine biotic index, M-AMBI = multivariate AMBI, BQI = Benthic quality index

spectrum. The optimal suite of variables for assessing enrichment status comprised two of the best performing biotic indices based on alternative / independent classification schemes (*i.e.* AMBI and BQI) coupled with total abundance and a geochemical variable (preferably TFS). Although %OM provides useful information about 'organic loading' at low-flow sites, it can be unreliable as a predictor of enrichment, and tends not to respond at high-flow sites where resuspension plays a significant role (Keeley *et al.* 2013a, 2013b).

2.1.2. Integration of variables and enrichment stage

After indicators are selected, the next critical step is ensuring that the results can be meaningfully interpreted. As outlined in Report 2, many existing fish farm consent conditions specify environmental expectations (or standards) based on narrative descriptions. Results can therefore be ambiguous and difficult to interpret with respect to compliance. Recent efforts have moved toward interpreting these in a quantitative way with the aid of the enrichment stage gradient and the integration of multiple variables. The result has been a primary reference to an overall enrichment stage (ES) as well corresponding thresholds for some of the more reliable and useful individual variables. The thresholds for individual variables can be used in isolation; however, a weight-of-evidence approach is a far more robust way to determine compliance. It reduces the risk of an excessive or inadequate management response due to an anomalous result.

In order to take a weight-of-evidence approach, it is necessary to combine the information from a variety of individual variables into an overall assessment of ES. This is conventionally achieved by the subjective process of expert judgment; however, an alternative approach has been developed by Keeley *et al.* (2012a, 2012b), whereby each of the variables is quantitatively defined against a common gradient that spans the full extent of enrichment, *i.e.* from natural/pristine conditions to an anoxic (no oxygen) and azoic (no organisms) situation.

In general, all of the variables vary in a relatively consistent manner along the enrichment gradient with distance from aquaculture farms. For instance, the abundance of organisms inhabiting the sediment (infauna) will typically peak in the region of moderate impact, whereas species diversity will steadily decrease with proximity to the farm and in the area of greatest organic enrichment (Figure 5). Similar patterns can be observed beneath shellfish farms; however, the effects are generally less intense beneath the farms.

General descriptions and quantitative relationships (*i.e.* for low-and high-flow sites[2] in the Marlborough Sounds, Keeley *et al.* 2012a) are provided for each variable, unless the analysis determined that there was no significant difference. Using those

[2] The initial criteria proposed for classification of low-flow *versus* high-flow is whether the mid-water current speeds are below or above 10 m s^{-1}, respectively.

relationships, the values for each of these variables can be converted to an equivalent ES score (value from 1.0 to 7.0) which can then be combined quantitatively (by averaging) to arrive at an 'overall ES' that has an associated statistical variance. Hence, it is a multi-variable, 'weight-of-evidence' type approach. The ES score also assists in minimising influence of any single variable and provides an integrated measure by which to grade overall levels of ecological impact on the underlying seabed. This is the principle behind protocols used to assess the seabed condition for consent compliance purposes in the Marlborough Sounds, and a similar approach is readily transferable for application in the Waikato CMA.

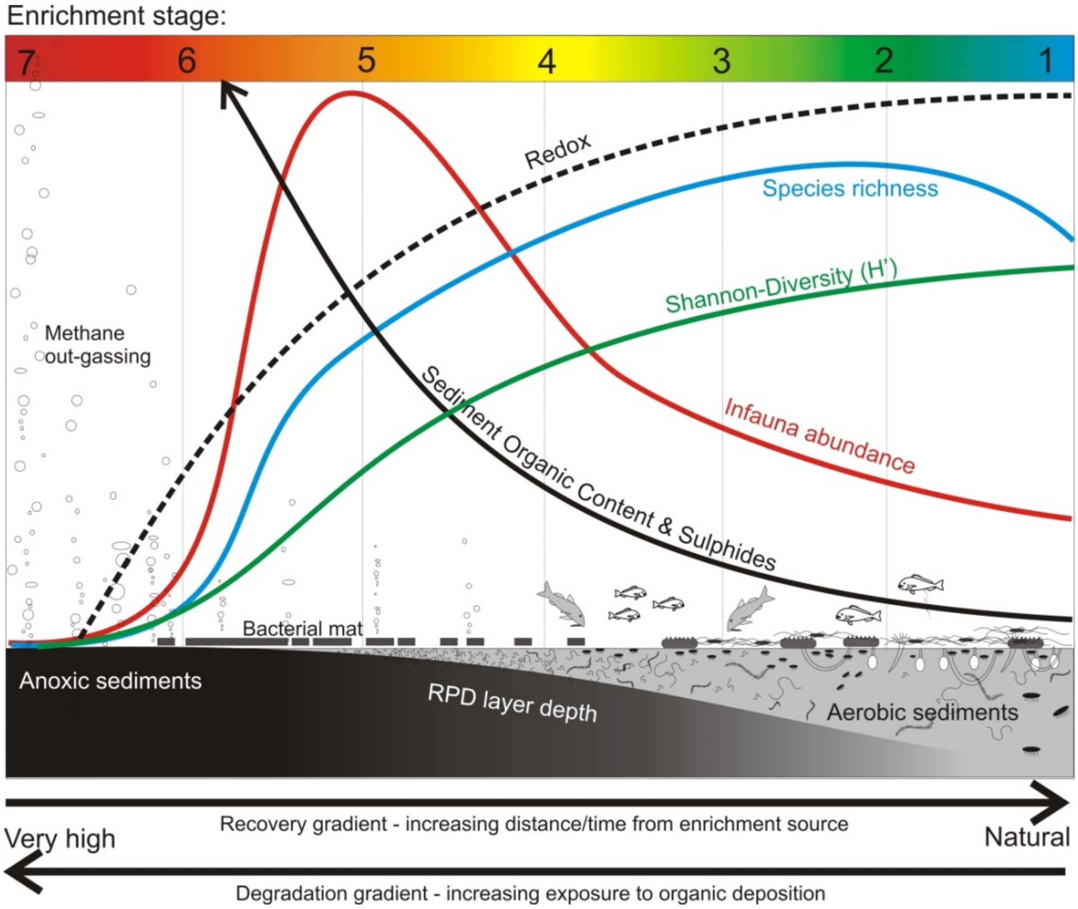

Figure 5. Stylistic representation of the enrichment stage (ES) gradient with typical responses of individual variables according to proximity to the farm (from very high impact (on the left) to natural conditions (on the right)).

Table 1 General descriptions and primary environmental characteristics for the seven enrichment stages (see Keeley *et al.* 2012a, 2012b). HF = high-flow sites (≥ 10 $cm.s^{-1}$), LF = low-flow sites (< 10 $cm.s^{-1}$).

	General description		Environmental characteristics
1	***Natural/pristine conditions.***	LF	Environmental variables comparable to an unpolluted/un-enriched pristine reference station.
		HF	As for LF, but infauna richness and abundances naturally higher (~2 × LF) and %organic matter (OM) slightly lower.
2	***Minor enrichment.*** Low-level enrichment. Can occur naturally or from other diffuse anthropogenic sources. 'Enhanced zone.'	LF	Richness usually greater than for reference conditions. Zone of 'enhancement' – minor increases in abundance possible. Mainly a compositional change. Sediment chemistry unaffected or with only very minor effects.
		HF	As for LF
3	***Moderate enrichment.*** Clearly enriched and impacted. Significant community change evident.	LF	Notable abundance increase; richness and diversity usually lower than reference station. Opportunistic species (*i.e.* capitellid worms) begin to dominate.
		HF	As for LF
4	***High enrichment.*** Transitional stage between moderate effects and peak macrofauna abundance. Major community change.	LF	Diversity further reduced; abundances usually quite high, but clearly sub-peak. Opportunistic species dominate, but other taxa may still persist. Major sediment chemistry changes (approaching hypoxia).
		HF	As above, but abundance can be very high while richness and diversity are not necessarily reduced.
5	**Very high enrichment.** State of peak macrofauna abundance.	LF	Very high numbers of one or two opportunistic species (*i.e.* capitellid worms, nematodes). Richness very low. Major sediment chemistry changes (hypoxia, moderate oxygen stress). Bacterial mat usually evident. Out-gassing occurs on disturbance of sediments.
		HF	Abundances of opportunistic species can be extreme (10 × LF ES 5.0 densities). Diversity usually significantly reduced, but moderate richness can be maintained. Sediment organic content usually slightly elevated. Bacterial mat formation and out-gassing possible.
6	***Excessive enrichment.*** Transitional stage between peak abundance and azoic (devoid of any organisms).	LF	Richness and diversity very low. Abundances of opportunistic species severely reduced from peak, but not azoic. Total abundance low but can be comparable to reference stations. %OM can be very high (3–6 × reference).
		HF	Opportunistic species strongly dominate, with taxa richness and diversity substantially reduced. Total infauna abundance less than at stations further away from the farm. Elevated %OM and sulphide levels. Formation of bacterial mats and out-gassing likely.
7	**Severe enrichment.** Anoxic and azoic; sediments no longer capable of supporting macrofauna with organics accumulating.	LF	None, or only trace numbers of infauna remain; some samples with no taxa. Spontaneous out-gassing; bacterial mats usually present but can be suppressed. %OM can be very high (3–6 × reference).
		HF	Not previously observed - but assumed similar to LF sites.

2.1.3. Implementing a 'zones' approach

Enrichment stage (ES) scores vary along a gradient based on proximity to aquaculture farms. We therefore recommend applying a 'zones' approach for establishing monitoring sites and assessing spatial extent of effects, which will in turn vary depending on the physical characteristics of a farm site. Up until 2014 in the Marlborough Sounds, zoned monitoring of traditional 'low-flow' farm sites occurred at or beneath the net pens, at 50 m and 150 m away in a down current (worst-case scenario) direction (Figure 6). At high-flow sites the distances are greater, in order to accurately gauge effects over larger areas associated with the dispersive nature of these sites. Reference sites are also monitored in conjunction with each farm. Thus, the distance to monitoring stations and the associated seabed quality standards are critical components of any consent monitoring programme.

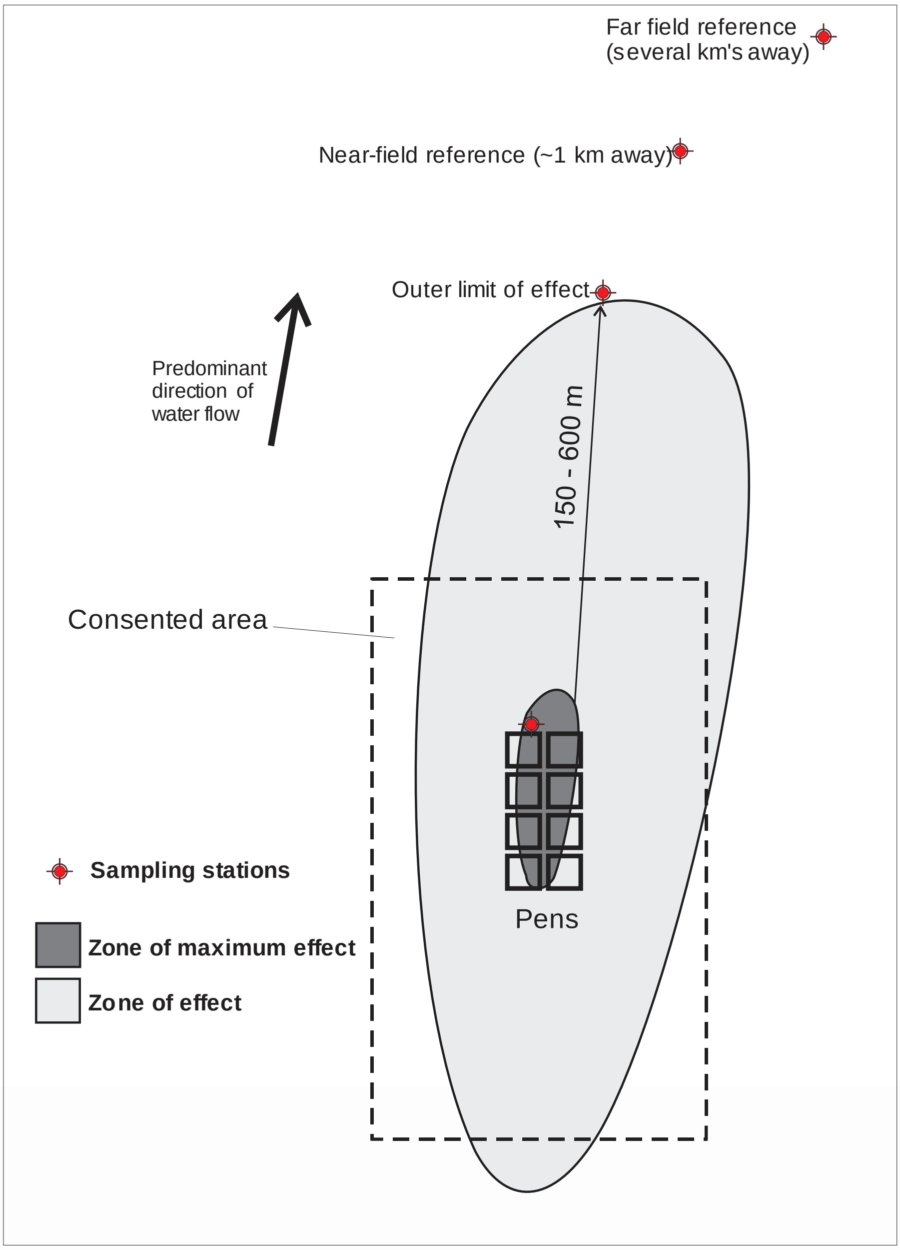

Figure 6. Schematic showing the application of seabed effects zones to aquaculture, with compliance at zone boundaries regulated by environmental quality standards and sampling at set stations with varying proximity to pen structures.

2.2. Determining baseline conditions

The first step in evaluating the appropriateness of indicators and setting suitable EQS for monitoring aquaculture effects is to review existing, relevant environmental data to quantify the baseline conditions that will be impacted. Such information is not only critical to assessing the effect of existing and future aquaculture farms, but also for gauging the extent to which other stressors and broader-scale issues may be affecting conditions in the CMA. This section focuses on characterising baseline conditions at a number of sites in the Firth of Thames and near the Coromandel Peninsula, where the vast majority of aquaculture occurs in the Waikato CMA, and consequently, with the largest datasets available. We first characterise the Firth of Thames seabed environment by comparing data from here to other established marine farming areas, and then review the sufficiency of data (in particular macrofauna data) for the application of established biotic indices of seabed enrichment from aquaculture (Borja *et al.* 2009, Keeley *et al.* 2012a). The data are used to estimate ES scores for several farming zones, thereby providing a baseline from which to gauge levels of likely change and set appropriate EQS (see Section 2.2.4).

2.2.1. Data type, intensity and spatial coverage

A summary of recent surveys conducted in the Firth of Thames that contain benthic habitat information is provided in Table 2. The information found to date includes four particularly useful studies, all of which were conducted in the last three years. Data in these reports pertain to the outer Coromandel Marine Farming Zone (CMFZ), Wilson Bay Marine Farming Zone (WBMFZ) Area B (as part of a Fishery Resources Impact Assessment (FRIA) and baseline monitoring for mussel aquaculture), and a variety of mussel farms and reference sites situated in the Coromandel region (see Figures 2 and 3). Information outside of the main existing and proposed marine farm areas is sparse and limited to control sites or spatial gradients within close proximity to those farms. Aside from the 3-yearly monitoring of WBMFZ Area A, which focusses largely on sediment profile imagery, there is no apparent location where regular, consistent long-term monitoring has taken place such that historical trends and temporal variability could be evaluated.

Nonetheless, the data and information appear to be sufficient to describe the baseline characteristics for those areas as well as the types of communities that typify mild enrichment normally associated with mussel farms. Types of data include macrofauna taxonomy, sediment grain size, total organic matter content (TOM), redox discontinuity depths, sediment nutrient concentrations, sediment profile imagery (SPI) and some visual information on epifauna (*e.g.* seastars). The type of information collected is inconsistent between surveys and areas, and lacks background data on some key indicator variables including total free sulphides and redox values for natural and moderately enriched sediments, and baseline trace metal concentrations; especially for copper and zinc, which are associated with fish farm discharges.

Table 2. Summary of Firth of Thames (and inner Hauraki Gulf) datasets containing seabed information.

Note: Coromandel Marine Farming Zone (CMFZ), Wilson Bay Marine Farming Zone (WBMFZ), Fisheries Resource Impact Assessment (FRIA).

Data owner	**Location**	**Dataset and purpose**	**Variables**	**Number of samples**	**References**
WRC	CMFZ	Coromandel marine farming zone (CMFZ) baseline	Macrofauna, photo-quads, grain size, TOM, *chl*-a	26 systematically placed stations	Needham & Pilditch (2012) Paavo (2012)
Ministry of Primary Industries	Wilson Bay Area B	FRIA (pre-development)	Depth, grain size (4 groups), %OM, redox depth, macrofauna	20 sample stations along 5 N-S transects. Triplicate samples	Stenton-Dozey *et al*. (2008)
Area B Compliance Ltd	Wilson Bay Area B	Baseline (pre-development)	TN, TP, OC, grain size (6 groups), macrofauna	6 transects: 2 Nth, 2 Sth, 1 W, 1 E 61 sample stations	Clearwater *et al.* (2012)
Ministry of Primary Industries	Outer Firth of Thames	CMFZ initial investigation	Side-scan, video, epi-benthic sled	-	Grange *et al.* (2011)
Group A Consortium Wilson Bay	Wilson Bay Area A	Testing SPI, monitoring effects	SPI, %OM, grain size	6 - 8 stations	Clearwater (2010)[3]
NIWA, Group A Consortium Wilson Bay	Wilson Bay Area A	Comparison of SPI and laboratory sediment analyses	SPI, DO and pH sediment profiles, sediment-water fluxes, porewater nutrients, benthic macrofauna	6 stations	Giles *et al*. (2012)
Sealords; Tom Hollings	Variety of Coromandel farms	Mussel farm extension assessments	Depth, TKN, TON, TN, TOC, grain size (4 grps), macrofauna	42 stations – farms and controls (controls in triplicate)	Taylor *et al*. (2012)
Coromandel MFA	MF364 Coromandel Harbour	Benthic assessments of existing farm	Depth, TKN, TON, TN, TOC, grain size (4 grps), macrofauna	9 single farm stations	Dunmore *et al.* (2012b)
Auckland University of Technology	Eastern Waiheke Is.	MSc thesis; mussel farm effects on benthos	Grain size, macrofauna	~200	Wong (2009)[4]

[3] Wilson Bay Marine Farming Zone Area A Monitoring 2010 using Sediment Profile Imagery (SPI). NIWA Client Reprot HAM2010-108. Prepared for Group A Consortium.
[4] The effects of green shelled mussel mariculture on benthic communities in Hauraki Gulf. MSc thesis School of Applied Science, Auckland University of Technology Source: http://aut.researchgateway.ac.nz/bitstream/handle/10292/663/WongC.pdf?sequence=5

2.2.2. Seabed characterisation

Macrofauna data from the WBMFZ Area B FRIA and baseline sampling, CMFZ baseline sampling, and a variety of Coromandel mussel farms and reference sites have been collated and preliminarily reviewed. Some initial observations of the basic environmental indicators with implications for enrichment tolerance and setting standards are as follows.

- The sediments at the WBMFZ Area B are predominantly silts (about 48%) and clays (about 32%). The fine composition of these sediments has implications for the permeability and vertical distribution of oxygen in the sediments and therefore macrobenthic activity and production.
- Seabed diversity in the WBMFZ Area B appears to be relatively low with an average of around 10 taxa and 20 individuals per core. The FRIA data from this location had extremely low abundance and richness, with 1-5 species and a total abundance of only 3-14 individuals. To put this into context, low flow areas within the Marlborough Sounds (in similar depths and substrates) tend to have around 20-30 taxa and an abundance of 50–100 individuals, and high-flow sites can have 30 to 40 taxa and abundances of 100–200 individuals. This has potential implications for the way in which the benthos may respond to organic enrichment and the productivity and waste assimilation potential.
- The outer CMFZ site also has relatively low richness and abundance where there is on average approximately 12 taxa and 30 individuals per core. However, the benthos at this site appears to be relatively balanced and unmodified at present.
- The sediments at CMFZ have a greater fine and medium sand component (clay, 39%; fine sand, 27%; medium sand 22%) indicative of stronger currents and a potentially more productive seabed than within the inner Firth.
- Total organic matter (%OM) appears relatively high in both areas at 7% to 8% (maximum 11 %). By comparison, low flow areas in the Marlborough Sounds are typically around 6%, while high flow areas are 3.5%. This suggests that the existing levels of organic deposition may be relatively high; hence the fauna should be at least partially predisposed to organic inputs.
- In contrast to the WBMFZ and CMFZ, locations in and around mussel farms near Coromandel had very low %OM (0.5 to 2%) and a relatively diverse and abundant macrofauna (on average about 20 taxa and 90 individuals per core).

In general, these existing data suggest that the locations range along a gradient from a more impacted, organic enrich environment within WBMFZ to a generally unimpacted (yet moderately high organic content) situation in the CMFZ to a relatively ‘pristine’ condition near the Coromandel Peninsula. These are preliminary observations and will be subject to further revision as more data and information becomes available.

2.2.3. Biotic indices

The biotic indices AMBI and BQI have been demonstrated to be good measures of seabed enrichment resulting from aquaculture activities (Borja 2009; Keeley *et al.* 2012a, 2012b). Both indices require knowledge about the enrichment / pollution / disturbance tolerance of individual taxa; the former utilizes Eco-Groups and the latter $ES50_{0.05}$ values (a species tolerance score based on Hurlbert's diversity measure, Rosenberg *et al.* 2004). These have been calculated for dominant macrofauna in the Marlborough Sounds and Eco-Group classifications are available from a centralised and continuously expanding global database (http://ambi.azti.es/). Robust calculation of AMBI requires that > 80% of the taxa within the sample have allocated classifications (Borja 2004). It is not essential that every taxa is classified, however, it is important that the numerically dominant taxa are.

The taxa contained within the samples from the WBMFZ Area B, CMFZ and Coromandel mussel farms have been cross-checked against the existing classifications. This enabled the following conclusions to be made.

- Average AMBI and BQI scores for the WBMFZ Area B macrofauna are about 1.5 (max 2.6) and 5.5 (9.7), respectively. Average AMBI and BQI scores for the CMFZ macrofauna are about 1.4 (max 1.7) and 8.5 (10.5), respectively. Hence, the macrofauna at CMFZ contains less disturbance/enrichment tolerant taxa, which is consistent with the differences in the seabed characteristics at these sites.
- On average, 88% of the taxa at WBMFZ Area B were able to have an Eco-Group classification assigned. However, approximately half the samples had < 80% of taxa allocated and some were as low as 50%. This is partly a function of the often very low taxa count (*e.g.* 3–6 taxa) which means two or three unallocated taxa represents a large proportion of the total.
- On average, 85% of the taxa at CMFZ were able to have an Eco-Group classification assigned. Seven of the 26 samples had less than 80% of the taxa assigned. Hence, reasonably reliable AMBI scores can be calculated presently for this location, but this will be strengthened by further research into the tolerance of a few key species (see Section 2.4).
- The majority of the taxa in WBMFZ Area B and CMFZ samples were Eco-Group I and II, which are either sensitive or indifferent to disturbance / enrichment. Very few first or second order opportunists were present. Nematodes and *Paraprionospio* sp. are two such taxa that are present and are likely to proliferate with enrichment; however, it is difficult to predict which other species might appear and become numerically important.
- Capitellids, which are a ubiquitous and reliable indicator of enrichment, were not present in either the WBMFZ Area B or CMFZ datasets, and were only occasionally observed in the samples from the established Coromandel marine farms.

- The BQI was able to be calculated for most of the datasets, however, more work needs to be done to determine $ES50_{0.05}$ scores for more of the local taxa to make this a reliable index for the region.

2.2.4. Enrichment stage scores

Data from four of the existing datasets (WBMFZ Area B Fisheries Resource Impact Assessment 2008 and Baseline 2012 (Stenton-Dozey *et al.* 2008; Clearwater *et al*. 2012), CMFZ 2012 (Paavo 2012) and Coromandel marine farms 2011 (Grange *et al*. 2011) were used to calculate preliminary enrichment stage (ES) scores and test whether variable specific relationships for determining ES may need to be tailored to the region. The regressions used in calculating ES were those developed for low flow environments in the Marlborough Sounds (Keeley *et al.* 2012a). Calculations of ES in this report are restricted to the available data and as such do not include any sediment chemistry information, which is normally a valuable complementary indicator to the overall assessment. Additionally, as noted above, some of the biotic indicators used (*e.g.* AMBI) are calculated without having Eco-Group allocations for some of the numerically important taxa. Therefore, the calculations provided here are useful indications but should be treated with caution.

All of the WBMFZ Area B data, but in particular the Fisheries Resource Impact Assessment data, indicated a very impoverished macrofaunal community, with both the number of taxa (S) and total abundance (N) typically in single digits (*i.e.* 0-10/core). From these data alone, it is difficult to establish what the appropriate reference values should be (*i.e.* what are S and N in pristine conditions?) and therefore the application of the existing relationships for these variables with ES cannot be applied. In the absence of these relationships, percent change in abundance curves derived for the Marlborough Sounds may be useful; however, the need for an appropriate, local baseline for referencing percentage change remains. What defines pristine seabed conditions in this environment? Do the conditions change spatially over the region regardless of aquaculture, or in proximity to other stressors that may also be impacting the CMA? The inability to answer these questions highlights the need for a broader-scale assessment of ES scores spanning the region where aquaculture currently takes place and where it is likely to occur in future (see Section 2.4). This will in turn assist in tailoring the ES approach for specific sites and the proper application of EQS within consent-based monitoring programmes.

The unusually low S and N values corresponded to very low richness and evenness scores; but the AMBI remained relatively low, indicating that the species that were present are not necessarily disturbance-tolerant. As such, the macrofauna and overall ES was surprisingly high for this dataset (ES = 4.1). Organic loading was moderately elevated (equivalent ES = 3.5; Table 3). These results may be due in part to inadequate sampling of the macrofauna community; however, they are indicative of a stressed environment where disturbances such as sedimentation are frequent or persistent, and succession in macrofauna species is repeatedly interrupted. If confirmed through additional sampling, these results have important implications in terms of how the benthos will respond to any substantial further increases in organic inputs.

Table 3. Mean equivalent enrichment stage (ES) scores for organic loading (based on %OM), sediment chemistry (normally based on sulphides and redox), macrofauna (based on macrofauna statistics and indices) and overall ES, which integrates information from all three groups. Values are the mean of all samples and 95% CIs are given for overall ES. *Values for Area B are not reliable due to potentially compromised data.

	Mean equivalent ES				
Dataset	Organic loading	Sediment chemistry	Macrofauna	**Overall (95% CI)**	Comments
WBMFZ Area B FRIA	3.5	NA	4.3	**4.1*** **(3.2, 4.9)**	Extremely low S and N (and strongly elevated %OM.
WBMFZ Area B Baseline	NA	NA	2.8 (1.5, 4.1)	**NA**	Based only on macrofauna. Low S and N. Some sites with only a few enrichment tolerant taxa = high level of disturbance.
CMFZ	3.2	NA	2.2	**2.5** **(1.9, 3.1)**	Low N but slightly higher S. Organic matter elevated. Balanced macrofauna community.
Coromandel					
Control sites	0.9	NA	2.1	**1.7** (0.9, 2.5)	Seemingly more naturally diverse and abundant samples. Very low %O.
Farms sites	1.2	NA	2.2	**1.8** (1.3, 2.4)	

Note: WBMFZ = Wilsons Bay Marine Farming Zone, FRIA = Fisheries Resource Impact Assessment, CMFZ = Coromandel Marine Farming Zone

There were stark differences between WBMFZ Area B and the samples that were collected around the marine farms closer to Coromandel (Table 3). The average overall ES from control sites around the Coromandel farms was 1.7, reflecting a relatively abundant and diverse macrofauna and very low %OM values. Similarly but less pronounced, the macrofauna in CMFZ 2012 samples were more abundant and diverse than the WBMFZ Area B samples and comprised a healthy balance of low Eco-Group (*i.e.* disturbance sensitive) taxa. As such, the overall ES for CMFZ samples was 2.5, indicating a healthy macrofauna community with low level enrichment (%OM was indicative of a depositional environment, with 5–9% w/w).

The above results for ES based on the existing data demonstrate a wide range of conditions likely exist across the region. As described in Section 2.4, more work is required to properly establish reference conditions and ensure all of the macrofauna regressions (including S and N) can be applied with confidence. This is especially important for the reliable identification of peak abundance, which is a key feature on the enrichment gradient.

2.3. Recommended protocols and standards for seabed monitoring

As described in Report 2, different forms of aquaculture lead to different types and levels of ecological effects; hence monitoring of aquaculture effects will vary in scope and effort depending on the form of aquaculture that is being monitored. The environmental quality standards (EQS) put in place to manage consents may also vary according to the type of aquaculture and the location where farming is occurring (*e.g.* since baseline conditions will vary across the CMA; see Section 2.2). Implicit in the application of EQS is the overall monitoring protocol, which guides what is required for various forms of aquaculture based on their potential to induce effects.

In this section we outline protocols[5] for use in the Waikato CMA and demonstrate how they can be used to inform monitoring processes, and determine action points and management responses in the context of EQS. We provide a protocol and indicative EQS for the two main categories of aquaculture: one for non-feed-added aquaculture such as farming of mussels and oysters and one for feed-added aquaculture such as finfish farms.

The application of different protocols and EQS according to different types of aquaculture could be construed as creating a double standard which is inconsistent or unfair. It could even be argued that the seabed effects from farming practices such as long-line mussel culture are sufficiently well understood, predictable and moderate, and that compliance standards are unnecessary. However, the justification is relatively straight forward: one of the key premises upon which non-feed-added forms of aquaculture are granted consent is that they are expected to result in only moderate levels of enrichment. Therefore, it is reasonable to expect that the activity will operate within the anticipated level of effects. However, as the effects are expected to be less severe, then the intensity of the monitoring can be appropriately reduced. For instance, seabed effects commonly observed beneath shellfish farms are relatively minor and the degree and extent of seabed monitoring that takes place can be limited accordingly, provided farming intensities are kept within limits[6].

The protocols described here are based on the fundamental aspects of monitoring farms in the Marlborough Sounds. Through a collaborative process, industry and

[5] For this purpose, 'protocols' refers to the process by which the monitoring occurs, the types of indicators to be assessed, and the responses and processes to be taken in the event of non-compliance.
[6] For example, small inshore shellfish sites (< 10 ha) typically have a close spacing of long-line structures (~5–10 m), whereas large offshore shellfish sites (> 1,000 ha) typically have long-line spacings of 50 m or greater. Guidance on what constitutes high and low intensity farming can be found in MPI guidance documents.

stakeholders have recently created a best management practice document (Keeley *et al.* 2014b) that includes a more definitive set of standards (referred to as environmental quality standards). Further information on the EQS process in the Marlborough Sounds and notable changes to the traditional monitoring protocol in the Sounds is provided in Appendix 1. Much of what has been learned in this process is integrated within the protocols described below.

The various types of aquaculture and the protocols used to monitor their effects can be divided into two broad types: non-feed-added and feed-added (Figure 7). We further separate non-feed-added aquaculture into two categories that encompass a diverse range of aquaculture types. Category A includes culture of smaller animals (spat) or more passive forms of aquaculture, whereas Category B includes those forms of non-feed aquaculture that involve the grow-out of adult shellfish with strong filter-feeding capabilities and relatively high densities or / or relative biomasses (per area of seabed). There are a range of possible farming scales and intensities, and across New Zealand these have varied from small-scale trials that do not require monitoring to full commercial farms. In the Waikato CMA, currently only commercial developments are permitted; an example of the definition of commercial farming in terms of scale and intensity is provided for both categories of non-feed-added aquaculture in Figure 7.

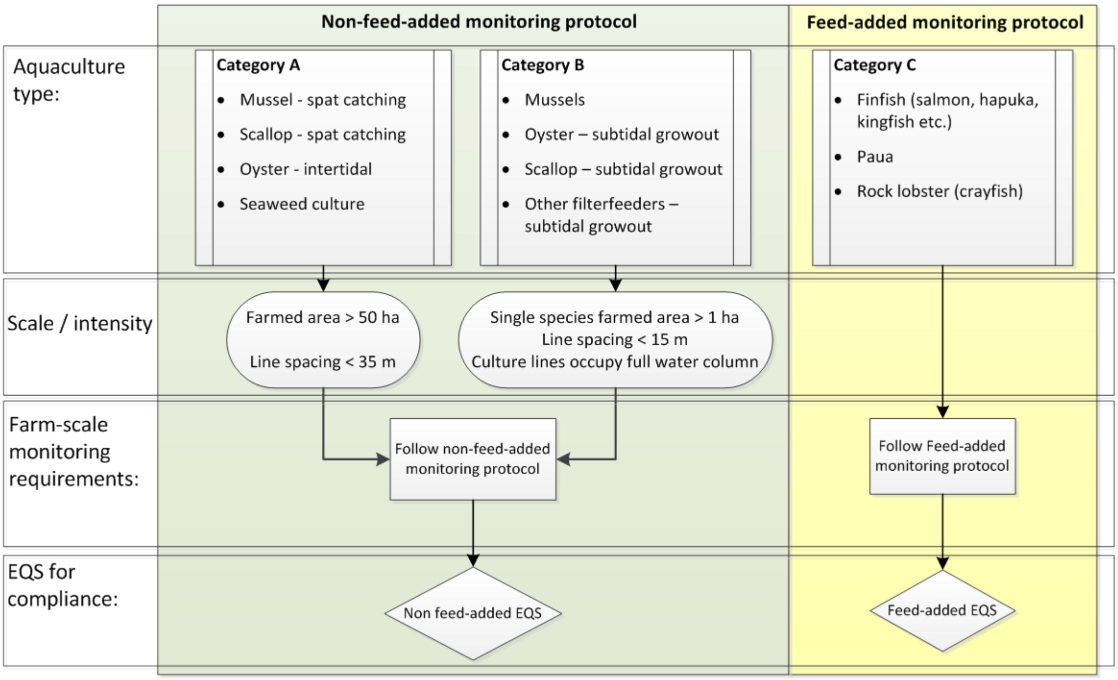

Figure 7. Flow diagram used to determine farm-scale monitoring requirements based on aquaculture type. An example is provided of the scale and intensity for commercial non-feed-added aquaculture that warrants the same level of monitoring across categories A and B. Monitoring for levels of farming intensity below the threshold shown would need to

be considered on a case-by-case basis and would likely fall below Level 1 requirements (see Section 2.3.1).

2.3.1. Monitoring protocols

A tiered approach is recommended for determining the monitoring required for all forms of aquaculture, where different levels of monitoring are required according to the type of aquaculture, and the history of the farm in terms of management and environmental performance. Such an approach is adaptive and encourages efficient monitoring and sustainable management practices. Matching monitoring intensity to production intensity and background environmental conditions are also consistent with approaches adopted overseas (Ervik *et al*.1997; Hansen *et al*. 2001; Wilson *et al*. 2009). Below we describe protocols according to non-feed-added and feed-added aquaculture that can be used to determine the level of monitoring required for a consented farm. Also provided is a brief description of what would be monitored at each level. Environmental quality standards for use in making decisions around monitoring requirements (and management response) are then presented in Section 2.3.2.

Non-feed-added

All non-feed-added forms of aquaculture are grouped by being required to comply with the same general EQS regardless of the level of monitoring required (see Section 2.3.2). A two-tiered protocol for deciding between two levels of monitoring is recommended for seabed monitoring[7] required for non-feed-added aquaculture farms (Figure 8). Both levels of monitoring would follow the approach described in Section 2.1, and examples can be found in environmental adaptive management plans (EAMPs) and monitoring reports for mussel farms in Nelson Bays (*e.g.* Forrest *et al.* 2012). For subtidal long-line culture of shellfish, the recommended samples to be collected and parameters measured include the following, with Level 1 monitoring requiring fewer sites and replicate samples than those required for Level 2 monitoring.

1. **Sediment physico-chemical characteristics:** Sediment samples are collected at a representative number of sites beneath areas, or ‘blocks’, being farmed and at reference locations. Samples can be collected using a remotely-operated grab or core sampler, or by divers using SCUBA. As described earlier in Section 2.1.1, sediment samples are analysed for **total free sulphides** (TFS, µM); **redox potential** (Eh_{NEH}, mV); **sediment texture** (as indicated by particle grain size fractions), **total organic content** (ash-free dry weight, AFDW), **total nitrogen** and **total phosphorus** of the upper 2 cm of the sediment.
2. **Infauna species and abundance:** A sediment infauna core (130 mm diameter × 100 mm deep) is collected from the same stations used to assess the sediment’s physico-chemical characteristics. The infauna core is washed through a 0.5 mm

[7] Monitoring of shellfish health is frequently aligned with the monitoring of seabed conditions beneath farms. Such monitoring is required in cases where the risk of disease and the transfer of disease from cultured and natural populations have been identified. Examples include combined seabed and shellfish health monitoring programmes for spat collecting and mussel farms in Nelson Bays.

sieve and the retained animals preserved. The organisms within the infauna core samples are then sorted, identified to the lowest taxonomic level practicable (*e.g.* species or family), and counted by trained and experienced staff.

3. **Epifauna species and abundance:** Conspicuous epibiota are quantitatively assessed from 20–30 randomly positioned photo-quadrats within a 20 m radius of each monitoring site. Benthic photo-quadrat images are taken with a high resolution camera. Images are analysed on a high resolution computer screen and conspicuous biological features like bacterial mats and burrows are identified (where possible). The density of shellfish on the seabed are also be enumerated from these photo-quadrats.
4. **Video / photographic and visual information:** Video footage and / or standardised photo-quadrats are taken along at least three transects (≥ 100 m) close to the benthic monitoring stations within farmed areas (beneath mussel lines) and at least one transect at two reference sites. Characteristics that can be assessed by remote video observation and/or photo-quadrats include general habitat type, holes and burrows, conspicuous epifauna, shellfish densities, evidence of sediment bioturbation, algal and bacterial mat development and sediment outgassing.

The type of samples that can be collected and methodologies used for intertidal oyster farms would be different than those above. For instance, photo-quadrats and video surveys would not be used for oyster farms where direct observations can be made. In cases where the intensity of farming is less than that considered commercial (see Figure 7), we recommend a relatively low level of seabed monitoring (Level 1). In addition, a low level of monitoring (and in some cases no monitoring) is recommended in situations where farming is only seasonal, as in the case of spat catching, or where farms have been in place for more than five years and the effects are well documented. In Nelson Bays for example, a low level of monitoring is currently required in spat collecting areas, and seabed monitoring in future will focus on farms involving grow-out to adult mussels (Keeley *et al.* 2014a).

We recommend a greater intensity of monitoring (Level 2) in cases where a farm is to be developed in a new area or region (*e.g.* outside of the WBMFZ or Coromandel area) and where the effects are not well documented. Large developments are often staged; in these cases a low level of monitoring may be required during early stages of the development, with a higher level of monitoring being carried out in the latter stages of development. Examples of this can be found in EAMPs developed for mussel farms in Tasman Bay (Keeley *et al.* 2014a).

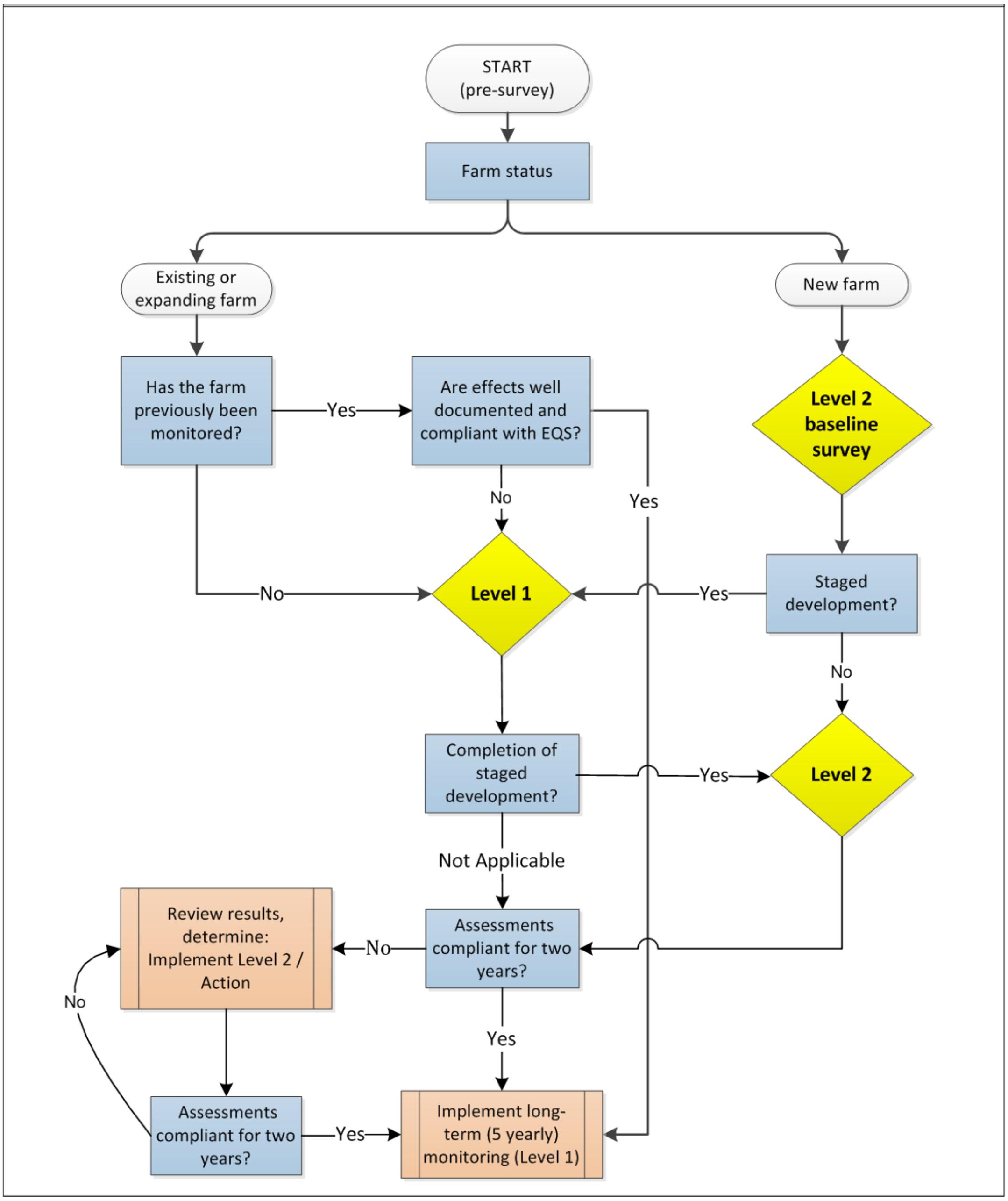

Figure 8. Proposed decision tree to determine the level of monitoring for non feed-added aquaculture consents.

There will likely be opportunities to combine monitoring efforts across multiple farms. This approach enables significant cost savings if sites within the effects zone of the farms and those outside (reference sites) can be shared. For example, only eight representative mussel farms out of the existing 32 farms around Coromandel Peninsula were monitored for baseline assessments relating to farm extensions (Taylor *et al.* 2012). In large farming zones such as WBMFZ, a similar approach can be taken whereby the various consents are pooled and the area is monitored as a whole. Considerable cost savings and better information for industry is also gained if assets such as moored monitoring platforms can be shared (see Section 4). A small, proportional cross-section of farms within reasonable proximity can also form a ‘regional network’ of sites and be monitored in a random, but regionally (or biogeographically) stratified manner on a five yearly basis. This can provide a facility for checking the state of the seabed in conjunction with specific farms in a low intensity, cost-effective way, and also contribute to our knowledge of potential wider ecosystem effects. Monitoring at sites within the network could be integrated with regional SOE monitoring (see Section 5).

Feed-added

A three-tiered protocol for monitoring is recommended for aquaculture farms involving the addition of feed. A decision tree is used to determine the level of monitoring required (Figure 9), ranging from Level 1, which involves rapid qualitative monitoring, to Level 3, which involves the full suite of benthic monitoring as described in Section 2.1. For example, a limited amount of qualitative monitoring (Level 1) would be required where the effects of a farm are well documented and have historically stayed within acceptable limits. Conversely, a new farm involving a high feed level and/or managing a farm at the upper limits of environmental thresholds would require a higher intensity of monitoring (Level 3) that provides greater precision and confidence in the results. Progression to less intensive monitoring (*i.e.* from Level 2 to 1) is contingent on how long the farm has been operational, whether feed levels have increased significantly, and whether the results of the previous years’ annual monitoring survey were compliant with the EQS (Figure 9). The three different levels of monitoring for finfish farms in the Marlborough Sounds have been described as follows:

- **Level 1** is the least intense form of monitoring. This approach places greater emphasis on qualitative indicator variables that can be rapidly evaluated and reported in about two weeks. It focuses on assessment at two to three monitoring stations, including one or two located at the outer limit of effects for low and high-flow sites, respectively, and one at a near-field reference location (see Figure 6 and Appendix 1).
- **Level 2** is the default level of monitoring at all farm sites and forms the basis for determining the level of management response required should the EQS be exceeded (see next section). Monitoring is conducted at two or three stations within the zone of maximum effects, one or two stations at the outer limit of effects (flow dependent), and at near-field and far-field reference locations. Five replicate samples of the full suite of quantitative variables are collected from each station (see Section 2.1). Three of the samples are processed initially; the remaining two samples can be processed if greater certainty is required (*e.g.* in the event that the standard error exceeds the maximum permitted EQS).
- **Level 3** is the most intensive type of monitoring with a flexible spatial design that aims to elucidate spatial patterns (*e.g.* footprint mapping), or address specific concerns. It is conducted at year 0 (baseline) and after five years of operation at

full capacity, and then as necessary according to the decision tree. The methods used to conduct these surveys are unspecified as they are likely to evolve with time. In effect, this is an avenue for gaining a better understanding of the causal factors (farm-based and otherwise) and a meaningful plan to avoid non-compliance—an adaptive management response. Two anticipated forms of Type 3 sampling design are:

- o Sampling regularly along radial transects to review whether the spatial arrangement of monitoring captures the zone of maximum effect.
- o Sampling over a grid pattern to map the distribution and extent of the habitats and resulting footprint, *e.g.* a pre-farm baseline or after five years to cross-check actual against predicted footprint.

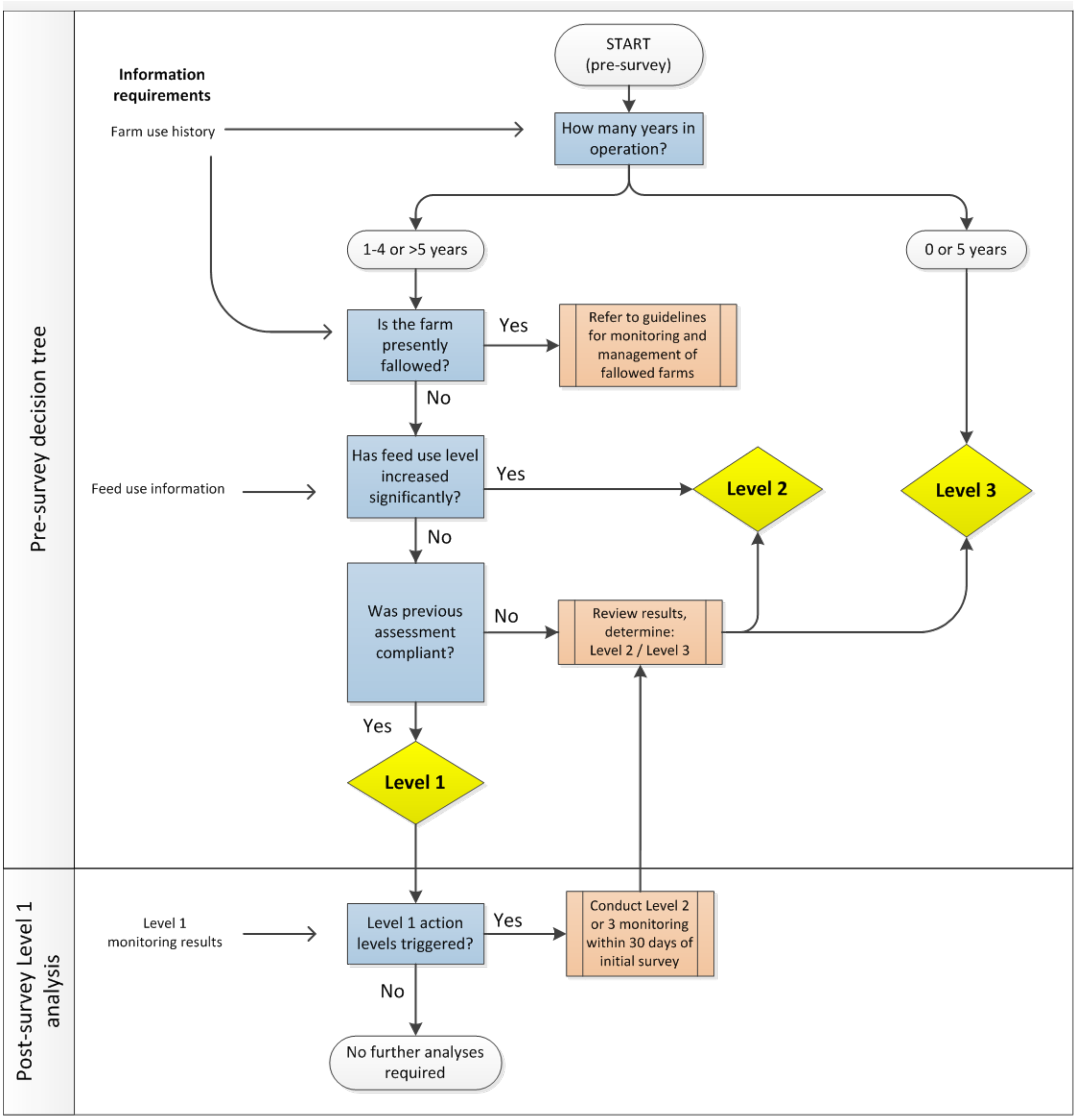

Figure 9. Proposed decision tree to determine the level of monitoring for feed-added aquaculture consents.

2.3.2. Environmental quality standards

Environmental quality standards (EQS) are necessary for ensuring compliance and implementing management actions. While identifying overall ES is a sound conceptual way to approach setting standards, confident quantification of ES requires knowledge of the relationships to each of the main indicator variables. It is also important that the approach is tested for a new environment where it has not been applied previously (see Section 2.2.4). This is because some of the responses of the seabed to enrichment can vary in different regions and may be site-specific, and because most new sites will lack existing information about how the seabed responds to very strong enrichment. In particular, sufficient information is needed in order to determine when the seabed is likely to exceed an ES score of 5, which is when peak abundance of macrofauna occurs in the Marlborough Sounds. The process of determining ES-based standards for the Waikato region will incorporate factors such as baseline values, natural variation and decisions of what is deemed acceptable. Values for EQS may differ from those in the Marlborough Sounds and may also differ throughout the region. The existing spatial variability in baseline conditions and ES (see Table 3) confirms that the predisposition of the seabed to aquaculture effects will vary depending on location. This highlights the importance of obtaining wider characterisation of seabed conditions across the Waikato CMA prior to robust calculation of ES and implementation of EQS for managing aquaculture consents (see Section 2.4).

In order to provide for the controlled development of the activity (avoiding the onset of adverse conditions), while allowing the actual effects to be quantified, some preliminary standards using the basic indicator variables are recommended. The data obtained during the implementation phase of the protocol can then be used to test the applicability of existing ES to environmental variable relationships and to derive site or region specific ES where necessary. This general process is summarised in Figure 10. A mature site-specific standards phase is expected to involve the development of an evolved monitoring protocol along the lines of that provided in Appendix 1.

The preliminary EQS developed for feed-added aquaculture is essentially the same for all forms of non-feed-added aquaculture (Table 4). The standards assume a moderate-to-highly enriched state is permitted beneath the farm and anywhere within the consented area (referred to as the zone of maximum effects; ZME), but natural conditions must be achieved within 100 m of the farm (outer limit of effects; OLE). A moderate-to-highly enriched seabed is denoted by ES 4.0 with corresponding specific thresholds given for: number of taxa, AMBI, TFS and the total qualitative score (Table 4). A similar approach is taken for the OLE station, but with the thresholds corresponding to 'moderate enrichment' and conditions comparable to a relevant (and appropriate) reference site.

Table 4. Recommended initial environmental quality standards (EQS) for enrichment stage (ES) scores and biotic indices associated with feed-added and non-feed-added forms of aquaculture. If any of these criteria are met (*i.e.* the criteria specify the non-permitted state) it would then lead to a response/action to meet compliance. An example of sampling stations within the zone of maximum effects (ZME) and outer limit of effects (OLE) for feed-added aquaculture is shown in Figure 6.

	EQS	
Sampling station	**Feed-added aquaculture**	**Non-feed-added aquaculture**
Zone of maximum effects (ZME)	**Overall ES > 5.0** -TFS > 1,500 µM -Total qualitative score > 6[a] -Macrofauna qualitative score > 2 -AMBI > 5.6 -Two or more replicates with no taxa present -Bacterial mats visible -Obvious spontaneous outgassing	**Overall ES > 4.0** -Number of taxa < 50% of reference site -AMBI > 4.3[b] -TFS > 1,000 µM -Total qualitative score > 1[c]
Outer limit of effects (OLE)	**Overall ES > 3.0** AND Comparable to relevant reference site -TFS > 500 µM[d] -Redox < 100[e] -Total qualitative score > 0	**Overall ES > 3.0** AND Comparable to relevant reference site -TFS > 500 µM[d] -Redox < 100[e] -Total qualitative score > 0

[a] Refer Appendix 1, Table 2

[b] Roughly equivalent to early onset of ES4 conditions and represents transition between 'moderate' and 'poor' ecological quality status (Borja *et al.* 2000).

[c] Refer Appendix 1

[d] Corresponds to the transition between Oxic-A and Oxic-B status (Hargrave *et al.* 2008).

[e] Consistent with SEPA 'action level *within* allowable zone of effects' (SEPA 2005)

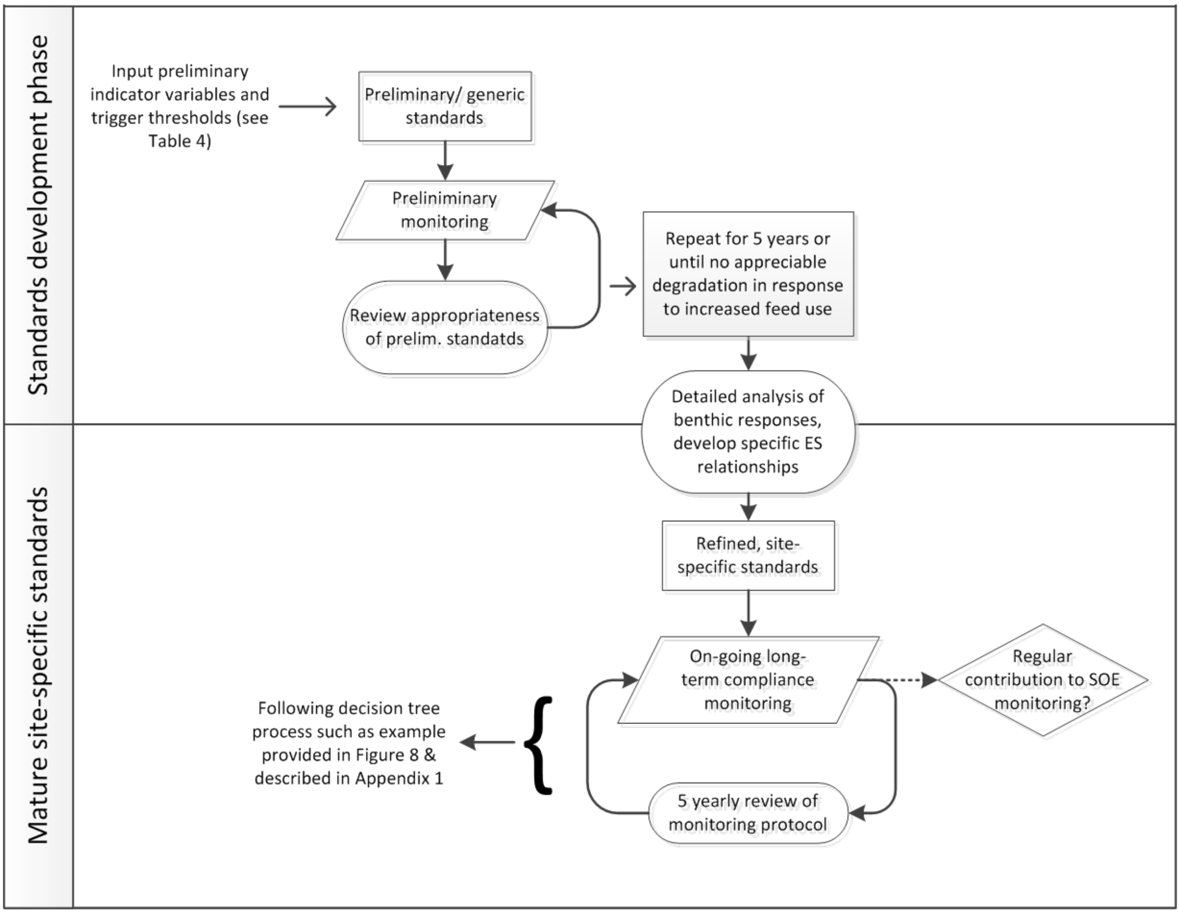

Figure 10. Suggested framework for evolution and refinement of environmental quality standard (EQS) and enrichment stage (ES) model for Waikato region. Note: The decision-making process and criteria upon which ongoing monitoring may be conducted is in the process of being developed for NZ King Salmon and Marlborough District Council by a targeted working group (see Appendix 1).

2.4. Remaining gaps to be filled prior to implementing environmental quality standards

There are a number of information gaps that need to be filled to better determine baseline conditions, and to validate appropriate EQS for the Waikato CMA. These can be divided up into gaps that can be filled using existing information and those requiring collection of new data and information.

The following existing information may be available to better describe baseline conditions:

- small-scale sediment surveys in the WBMFZ (Giles & Budd 2009)
- Wilson Bay Interim Aquaculture Management Areas Final Evaluation Report (Ministry of Fisheries 2009)
- other additional information pertaining to macrofauna in Wilson Bay Area A

- impact assessments from enriched areas (held by WRC). For example: outfall discharges (effluent, waste water, fish processing plants *etc*.) to Firth of Thames and Coromandel Harbour.

A fundamental gap in the information collected to date is a description of how the sediments respond to severe enrichment in different locations. This can be inferred to some degree from other regions; however, new site-specific information will provide added confidence in the evaluation of indicators and for setting environmental standards for on-going management. In particular, it would be valuable to obtain ecological tolerance information for the following taxa (in reducing order of importance) which were often numerically important in the samples collected in the CMFZ: *Labiosthenolepis laevis*, *Leionucula strangei*, *Torridoharpinia hurleyi*, *Neilo australis*, *Apodidae* spp., *Pleuromeris zealandica* and *Lepidastheniella comma*.

It is also important to determine what constitutes a 'pristine' or unimpacted soft-sediment habitat in the region. This information is important for evaluating levels of effects and future changes, as well as for setting reference conditions for some biotic indices (*e.g.* M-AMBI, Muxika *et al.* 2007). The CMFZ samples may be useful for this purpose, and reflect a pristine location. However, this assumption would need to be confirmed by conducting a spatial survey of the benthic habitats to determine ES levels throughout the Firth of Thames, CMFZ and inner Hauraki Gulf. For example, it may be that a gradient exists with decreasing disturbance / enrichment levels along a gradient from the inner to outer Firth of Thames. Understanding spatial patterns in the ecological habitats would provide a sound basis for establishing appropriate reference sites and for understanding the regional processes at work and managing the area in to the future.

3. MONITORING WATER-COLUMN EFFECTS

It is widely known that critical water column processes such as nutrient cycling and levels of primary production may be affected through aquaculture activities (see Report 2). As in the case of effects on the seabed, the nature and extent of water-column effects related to these processes will depend on the type and intensity of aquaculture (*e.g.* shellfish farms versus fish farms that involve addition of feed). Similarly, effects on the water column can be separated into those occurring at the local-scale (within hundreds of metres of a farm), and broad-scale effects such as those resulting from nutrient enrichment from multiple farms.

As described in Section 2, effects on the underlying seabed from aquaculture can be measured and quantified using proven methods, while protocols incorporating standards can be implemented for managing aquaculture activities. Developing a similar approach to managing effects in the water column is more challenging, but nonetheless important since aquaculture has the potential to strongly influence the wider marine ecosystem. Ultimately aquaculture requires good data and information on water quality[8] to manage and maintain healthy and productive stocks; water-column monitoring serves purposes beyond managing for ecological effects.

In this section, we provide a brief overview of the water column environments in the Waikato CMA for regions where data currently exists and studies have been conducted (*e.g.* Firth of Thames; Appendix 2). This information is used to scope what monitoring should be required for the purpose of managing consents, versus monitoring required for assessing broad-scale effects and cumulative environmental change (as described in Section 4). We then identify aspects to consider in developing water-column monitoring protocols and standards for managing consents in the Waikato CMA.

3.1. Existing data and knowledge

Marine environmental data collection in the Waikato CMA has largely been carried out as part of resource consent monitoring requirements (see Report 1). Despite limited consent-related monitoring and virtually no SOE monitoring of the water column, there have been previous studies conducted in the Waikato CMA that provide knowledge on existing water column conditions.

Previous studies include past research in relation to development of mussel aquaculture in the Firth of Thames. This is described in WRC technical reports (*e.g.*

[8] Water quality is described by water column attributes that are important to sustaining life, such as levels of dissolved oxygen and nutrients, and water clarity (suspended sediments, turbidity) which affects light penetration. Water quality is also affected by contaminants, such as trace metals or pathogens associated with faecal contamination.

Broekhuizen *et al.* 2005; Zeldis 2008; Giles 2010) and other reports or publications (*e.g.* Giles *et al.* 2006; Chamberlain & Stucchi 2007; Taylor *et al.* 2012). Available coastal datasets from the Waikato Coastal Database[9] are summarised in Appendix 2. Many of the datasets listed are privately held; however publicly-available data summaries likely provide enough information for general descriptions of existing conditions around the Wilson Bay Marine Farming Zone (WBMFZ; Stenton-Dozey & Zeldis 2012) and outer region around the Coromandel Marine Farming Zone (CMFZ; Zeldis *et al.* 2010).

To date, monitoring of water-column effects from aquaculture in the Waikato CMA has focused on the WBMFZ and the effects of mussel farming on the depletion of phytoplankton and the composition of plankton communities. More than eight years of monitoring involving intensive two-weekly plankton surveys (monthly since 2006) has not detected significant effects of mussel farms on plankton communities (Stenton-Dozey *et al.* 2005; Zeldis 2008; Stenton-Dozey & Zeldis 2012). A desk-top study utilising time series data and describing existing water column conditions has also been carried out to assess the suitability of the CMFZ for farming finfish (Zeldis *et al.* 2010). The report notes that the region varies considerably according to season with regard to thermal stratification (mixing of the water column), phytoplankton biomass, and concentrations of dissolved oxygen and nutrients.

These studies collectively demonstrate that the inner Hauraki Gulf, including the Firth of Thames, displays variability in water column conditions that limits the ability to measure changes attributable to existing aquaculture in the region. This is similar to findings in the Marlborough Sounds, where larger-scale ocean and climate processes have been found to drive patterns in nutrient availability and primary production beyond the effects of aquaculture (Zeldis *et al.* 2008). These outcomes indicate that water-column monitoring for individual aquaculture consents needs to be integrated with other consent and SOE monitoring programmes in order to adequately capture reference conditions and wider, cumulative environmental changes that may be occurring. As discussed further in Section 4, tracking these wider and longer-term changes will in turn enable the aquaculture industry to respond accordingly to maintain productive farms into the future.

3.2. Recommendations for water-column monitoring for consents

Currently, an aquaculture consent holder is required to conduct a baseline survey and implement monitoring of water column parameters as listed in Appendix 1A of the WRC Coastal Plan. In the absence of any changes to monitoring requirements resulting from new recommendations, the water-column parameters listed in the WRC Coastal Plan according to farm type (extension, non-feed-added, feed-added) should

[9] http://waikatocoastaldatabase.org.nz/Home

be considered the 'default' monitoring requirements for consent applicants or holders. It is assumed that the level of requirements will vary on a consent by consent basis depending on the outcomes of the assessment of environmental effects, and specific attributes of a development including key environmental risks that have been identified. As discussed in Report 2, the latter will be influenced in large part by the size and type of the development and the characteristics of the site where the farm is to be located (*e.g.* water depth, currents).

Monitoring required of consent holders should produce data and information that aim to quantify the spatial and temporal extent and intensity of adverse effects associated with the consented activity, and in turn aid the management of the consented activity and minimisation of adverse effects. In order to meet these criteria, it is recommended that water-column monitoring required for consents focus on the local-scale where effects are measureable and can be attributable to a farm's activities. However, it is also recognised that the influence of individual aquaculture farms (regardless of type) combined with additional anthropogenic activities and natural stressors contributes toward cumulative, broad-scale effects on the wider ecosystem (see Report 1). As in the case of seabed monitoring, we recommend that broad-scale effects be addressed through integrated consent and SOE monitoring (Section 4), rather than require consent holders to address these farther afield effects on an individual basis. In addition, long-term SOE monitoring sites should be used and shared as a reference for local-scale monitoring for consents. The recommended approach of limiting consent monitoring to local-scale effects and utilising broad-scale SOE data may not always be feasible, such as when a significant development is proposed for an estuary or embayment that is far removed from existing developments and no data on baseline or reference conditions exist. In these cases, the consent holder will likely be required to monitor for broad-scale effects and collect adequate reference data beyond the influence of their development.

In regions such as the Firth of Thames and wider Hauraki Gulf, there is an opportunity to better integrate data collected at the local-scale as part of consents, and to use environmental data (*e.g.* reference sites) from larger-scale SOE monitoring programmes (see Section 5). Such integration and broader coverage of data and information is required to contextualise the role of aquaculture in wider cumulative environmental change. There is also opportunity in the region to combine multiple consent monitoring programmes through a consortium approach, as has been done to address assessments and monitoring of mussel farm extensions in the Coromandel (Taylor *et al.* 2012) and in WBMFZ areas A and B. As described in the following sections, the scope of water-column monitoring required of consents should vary according to the type of aquaculture (non-feed-added versus feed added) and a development's attributes (size, location, *etc.*) in order to align the types and level of effects with the appropriate types and level of monitoring.

3.2.1. Water-column monitoring for non-feed-added aquaculture

Existing aquaculture consents in the Waikato CMA allow culture of mussels and oysters. These non-feed-added forms of aquaculture lead to effects on the water column that are lower risk and different than those associated with feed-added aquaculture (refer Report 2). The main water column issue relates to the depletion of phytoplankton and zooplankton by filter feeding mussels and oysters, and effects on nutrient cycling due to the conversion of nutrients into different forms as a function of feeding (particulate versus dissolved forms of nitrogen). These effects are difficult to isolate from larger-scale processes and associated variability, indicating that shellfish culture has a small effect on water column processes within the context of other natural and anthropogenic drivers (Stenton-Dozey & Zeldis 2012).

Based on existing knowledge of the limited effects of non-feed-added aquaculture on the water column, it is recommended that consent monitoring of water-column effects only be required in the following situations[10]:

- When a single development, or combination of multiple farms, is of sufficient size relative to the water body and therefore has the potential to significantly influence the wider food web through feeding on plankton.
- When water-column effects are identified as a risk associated with a new farm development. This could occur when the size of the proposed development and stocking densities are high relative to the biophysical characteristics of an area (*e.g.* poorly flushed embayment, or phytoplankton concentrations are naturally low). Risk of effects on both the surrounding environment, and neighbouring farms, needs to be considered.
- When there is a high level of uncertainty due to a lack of data and information on existing conditions. For instance, when a significantly-sized mussel or oyster farm is being developed in an undeveloped area where no data or knowledge on water column conditions exist.

The recommended parameters for water-column monitoring required as part of consent conditions for non-feed-added aquaculture are listed in Table 5. Also included in Table 5 are additional parameters to those required by a consent that could be collected and integrated within a broad-scale SOE monitoring programme to contextualise effects of aquaculture on the wider marine ecosystem (see Sections 4 and 5). The collection of data for these additional parameters are only recommended if their collection at a newly consented site significantly strengthens a broader monitoring programme (*i.e.* the additional parameters do not need to be monitored everywhere). Parameters such as salinity and temperature are not appreciably affected by aquaculture farms; however, their measurement assists in quantifying

[10] Ultimately the requirements for monitoring will need to be assessed on a case-by-case basis and there may be situations beyond those listed that require monitoring.

important site characteristics such as water column stratification (mixing) and influence of freshwater inflows, both of which can affect the other parameters.

Table 5. Recommended water-column parameters for monitoring non-feed-added aquaculture consents. Also listed are opportune parameters beyond those required of a consent that could also be measured and would benefit a broad-scale state of the environment monitoring programme. All data would be required to go through a quality assurance process and be provided to council in a standardised format for transferability.

	Parameter	**Where should it be monitored?**	**When and how should it be monitored? (methods)**
Minimum required for consent	Salinity Water temperature Water clarity/turbidity Chl-*a*	Water column within the farmed area	At least monthly based on depth integrated water samples and/or conductivity, temperature, density (CTD) profiler, or continuously using fixed instrumentation
Opportune parameters that would benefit SOE monitoring	Total nitrogen Dissolved inorganic nitrogen (ammonia-ammonium, nitrate) Total phosphorus Dissolved reactive phosphorus	Water column within the farmed area	At least monthly water samples and laboratory analyses (integrated through water column or depth of stock)
	Dissolved oxygen saturation	Water column including near bottom	CTD profiler or continuously using fixed instrumentation

Contributing to a consortium approach to water-column monitoring is recommended when a farm of small size (*e.g.* Category A farms as described in Section 2) or farm extensions are placed within a water body where other farms already exist and there is sufficient water column data already being collected as part of another monitoring programme(s). In addition, water-column monitoring is likely not warranted for seaweed culture. As indicated above, depending on the location of the farm it may be advantageous to carry out water-column monitoring at the site to strengthen a broader-scale monitoring programme. Determining who carries out and resources the monitoring in this situation is beyond the scope of this report.

3.2.2. Water-column monitoring for feed-added aquaculture

Adverse water-column effects are most likely to arise from aquaculture involving addition of feed (see Report 2). It is recommended that water-column monitoring be required for all feed-added aquaculture consents. Consent monitoring should focus on the local-scale water quality issues that are directly linked to farm attributes that can be managed, such as stocking densities and feed inputs. Key parameters linked to these attributes include:

- Levels of **dissolved oxygen (DO)**, which can become very low with increased respiration by densely-farmed fish, combined with increased decomposition of feed and faeces on the seabed.
- **Ammonium** concentrations; dissolved nitrogen in the form of ammonium is excreted by farmed fish and becomes toxic to sea life when concentrations become too high.

All recommended parameters for water-column monitoring required as part of consent conditions, as well as additional ones that could be integrated within a broader-scale SOE monitoring programme are listed in Table 6. Although not currently used in New Zealand, feed-added aquaculture may also involve use of additives (*e.g.* trace metals, therapeutants, antibiotics). Some fish farms also have staff living on site, which results in 'greywater' discharge, and toilet or harvest effluents. No monitoring of additives and effects associated with effluent discharges is recommended since these issues can be mitigated through appropriate best management practices (BMPs), which are readily adopted by industry to maintain good water quality conditions for their farms (see Report 2).

Monitoring of parameters in Table 6 is aimed toward long-term monitoring of water column conditions. Depending on the level of uncertainty regarding an area to be developed (*i.e.* amount of baseline data), it may be necessary to require annual water column surveys that would coincide with seabed surveys (see Section 2). Results from such surveys can be used to validate effects assessments and quantify the effect of individual farms on the surrounding near-field water column environment where the potential for detecting change is greatest.

As an example, consent conditions for newly consented salmon farms in the Marlborough Sounds require NZ King Salmon to collect data on water column parameters at set stations coordinated with benthic monitoring stations at zone boundaries (see Section 2.1.3). At each station, depth profiles of salinity, temperature, chl-*a*, turbidity, and DO is measured *in situ* using a submersible sensor array (CTD: conductivity, temperature and depth) and water samples are collected for determining total nitrogen, ammonia-ammonium, and nitrate concentrations. The sampling design is based on monitoring the worst-case scenario at the pen edges, and then along the anticipated gradient at zone boundaries to assess near-farm mixing. An important consideration is that warmer water has the potential to influence feeding demands of cultured fish which in turn require greater feeding rates during these periods (see Buschmann *et al.* 2009). Targeted water-column monitoring should take into account any changes in feeding rates over the course of the year and be carried out during those times when feed usage is greatest.

Table 6. Water-column parameters required for consent monitoring for feed-added aquaculture. Also listed are opportune parameters beyond those required of a consent that could also be measured and would benefit a broad-scale state of the environment monitoring programme. All data would be required to go through a quality assurance process and be provided to WRC in a standardised format for transferability.

	Parameter	Where should it be monitored?	When and how should it be monitored? (methods)
Minimum required for consent	Salinity Water temperature Water clarity/turbidity	Water column within the farmed area and appropriate number of reference sites (if not covered by SOE monitoring)	At least monthly based on depth integrated water samples and/or CTD profiler, or continuously using fixed instrumentation
	Total nitrogen Dissolved inorganic nitrogen (ammonia-ammonium, nitrate)		At least monthly water samples and laboratory analyses (integrated through water column or depth of stock)
	Dissolved oxygen saturation	Water column including near bottom	Continuously using fixed instrumentation
Opportune parameters that would benefit SOE monitoring	Chl-*a*	Water column within the farmed area	At least monthly based on depth integrated water samples and/or CTD profiler, or continuously using fixed instrumentation
	Total phosphorus Dissolved reactive phosphorus		At least monthly water samples and laboratory analyses (integrated through water column or depth of stock)

3.2.3. Protocols and standards for water-column monitoring

Current water column standards for non-feed-added aquaculture for the WBMFZ is based on a 'limits of acceptable change' approach. In our opinion this approach cannot work based on the current level and spatial coverage of monitoring since changes in indicators such as chl-*a* will be driven by a number of natural and anthropogenic factors other than the aquaculture activity itself. This is similar to the situation with seabed effects, and the observation that conditions of the seabed show larger-scale patterns in organic enrichment and disturbance that are associated with stressors and processes beyond the scale of the aquaculture activities (see Section 2.2.4).

It is recommended that the current water-column monitoring associated with the WBMFZ be streamlined and integrated within a wider SOE monitoring programme that involves measurement of indicators across a larger region of the Waikato CMA (see Sections 4 and 5). This will enable a better assessment of what changes may be occurring in the Firth of Thames that may be associated with aquaculture.

Based on data from previous studies and data collected in the Firth of Thames, we recommend the following two standards for feed-added aquaculture in the WBMFZ and CMFZ:

1. To not cause reduction in DO concentrations to levels that are potentially harmful to marine biota. A suitable lower trigger value (or standard) might be if DO levels fall below 70% for a set consecutive period (*e.g.* 2 days), or if there is an observed downward trend.
2. To not cause elevation of nutrient concentrations outside the confines of natural variation for the location beyond a mixing zone of 250 m from the edge of the net pens. For ammonia, levels within the farm should not exceed ANZECC guidelines for toxicity.

Additional standards regarding the frequency, timing and intensity of phytoplankton blooms (including harmful algal blooms) may also be considered within a standards framework. However, we would recommend making these wider-ecosystem processes a component of the broader-scale SOE monitoring programme. We recommend two tiers of triggers in applying standards, with breaches of the first initiating further monitoring/investigation, and of the second to require a management response such as reduced stocking.

An example of water column standards for finfish farms exists in the recently drafted conditions for the New Zealand King Salmon Company Limited (NZ King Salmon) Board of Inquiry (BOI) plan change application[11] (see Box 1). The NZ King Salmon example for the Marlborough Sounds is not necessarily appropriate for the Waikato CMA or other aquaculture activities, but it highlights the level of detail that could be adopted to protect specific aspects of concern in the coastal water column environment. The NZ King Salmon water quality objectives refer to a wide range of targeted goals which are easily interpreted, but also provide a wider statement that the activities will be managed ‘to not cause a persistent shift from a mesotrophic to a

[11] Downloadable from: http://www.epa.govt.nz/Publications/Final%20Decision%20Vol2-Appendices-4-7.pdf

eutrophic state'. Some guidance as to what water properties constitute typical trophic states in coastal waters is available (*e.g.* Smith *et al.* 1999), and there are a number of frameworks that can be used to assess trophic states or trends (see Section 4.1).

Box 1: Example consent conditions

The conditions of consent for the NZKS plan change application (NZKS 2012) provide water column objectives for managing salmon farming activities that state:

> The farm shall be operated at all times in such a way as to achieve the following qualitative Water Quality Standards in the water column:
> a) To not cause an increase in the frequency or duration of phytoplankton blooms (*i.e*. chlorophyll a concentrations ≥ 5 mg/m^3) [Note: water clarity as affected by chlorophyll a concentrations is addressed by this objective];
>
> b) To not cause a change in the typical seasonal patterns of phytoplankton community structure (i.e. diatoms vs. dinoflagellates), and with no increased frequency of harmful algal blooms (HABs) (*i.e*. exceeding toxicity thresholds for HAB species);
>
> c) To not cause reduction in dissolved oxygen concentrations to levels that are potentially harmful to marine biota [Note: Near bottom dissolved oxygen under the net pens is addressed separately through the EQS – Seabed Deposition];
>
> d) To not cause elevation of nutrient concentrations outside the confines of established natural variation for the location and time of year, beyond 250 m from the edge of the net pens;
>
> e) To not cause a persistent shift from a mesotrophic to a eutrophic state;
>
> f) To not cause an obvious or noxious build-up of macroalgal (*e.g*. sea lettuce) biomass … (Condition 51—NZKS 2012)

3.3. Remaining gaps to be filled prior to implementation

The primary gap to fill for water-column monitoring relates to understanding existing conditions so that any future monitoring can be used to effectively manage aquaculture consents. These data are also required to refine and implement standards, which may need to vary across different regions of the CMA due to a location's natural characteristics and gradients in existing conditions. Gaps according to key steps include the following:

- Collection of baseline data for determining the range of existing water column conditions in areas where aquaculture has been developed and is likely to be developed in future.

- Setting of preliminary standards, followed by continuous review/revision of standards as data and information (including SOE monitoring outcomes) become available.

The Council may want to consider the establishment of an advisory panel that reviews the implementation and revision of standards over time.

4. STATE OF THE ENVIRONMENT MONITORING

State of the environment (SOE) monitoring in the Waikato CMA is very limited at present (see Report 1). There is an opportunity to strengthen SOE monitoring and the usefulness of the data it provides by integrating consent monitoring for aquaculture, as described in the earlier sections, with Council monitoring efforts. Factors that would broaden and improve an SOE monitoring programme that aligns with consent monitoring include a framework for integration, selection of appropriate indicators, and a sampling design that captures the right spatial and temporal scales.

A framework for implementing and integrating consent-based and SOE monitoring programmes has been presented in the first two reports of this series (see Figure 2). The framework involves six interconnected components, with components Three and Four the most relevant for developing an SOE monitoring programme. Component Three involves identifying SOE requirements and ensuring that SOE monitoring supports consent monitoring, addresses other human influences, and captures wider environmental change.

Identifying and developing environmental indicators, standards for indicators, and the overall monitoring design comprise Component Four and are the focus of this section. Council SOE monitoring must cover a diverse range of complex processes occurring over a large area of catchments, estuaries and coastal waters extending 12 nautical miles offshore. We focus here on SOE monitoring that would be carried out in coastal waters and is of relevance (but not limited) to aquaculture, which is a priority for WRC. Ultimately the development, refinement and expansion of a regional SOE monitoring programme will be an iterative and adaptive process that must address a broad range of environmental issues and related policy and management goals.

4.1. Indicator approach to SOE monitoring in the Waikato CMA

As is the case for consent monitoring, we recommend using indicators in SOE monitoring in the Waikato CMA. These will enable assessment of the overall health and condition of the CMA and allow progress to be tracked to reach WRC's overarching environmental management and policy goals. Monitoring of indicators must be carried out over the long term and be sufficiently integrated across ecosystem components in order to contextualise changes resulting from anthropogenic activities and natural processes; this is also required for assessing cumulative effects. It is also recommended that indicators be integrated into a single index (or multiple indices) that can be used to assess the overall state of different regions within the CMA, including the condition of both the water column and the seabed. Monitoring of individual indicators can be informative, as in the case of measuring chl-*a*; however, integration of multiple indicators is recommended in most instances to provide a more stable and holistic measure of environmental conditions over time. The use of ES scores for assessing seabed effects is a good example of such integration (refer to Section 2).

4.1.1. Identifying environmental indicators and integrated indices

There are numerous indicators that are used in environmental monitoring of coastal waters and habitats. Many of these can be integrated into single indices that can be used to gauge the overall trophic status of the water column (*i.e.* water quality), as in the case of the trophic index TRIX (Table 7; Vollenweider *et al.* 1998). Indicators measured in both the water column and on the seabed can also be integrated into a single index, as in the case of ASSETS (Assessment of Estuarine Trophic Status), which incorporates indicators associated with primary symptoms of eutrophication such as dissolved nutrients and chl-*a* in the water column and secondary symptoms such as dissolved oxygen and coverage of seagrass (Bricker *et al.* 1999, 2003). In order to facilitate integration of SOE and consent monitoring, we recommend using the ES approach for monitoring seabed conditions in soft sediment habitats.

Table 7. Examples of coastal monitoring indices (adapted from Ferreira *et al.* 2011). Integrated indices are typically calculated on a seasonal to annual basis and are suitable for SOE monitoring rather than managing consents. Many indicators used in calculating the indices are measured more frequently (*e.g*. weekly to monthly for nutrients and chl-*a*) and can be used within consent monitoring (see Tables 5 and 6).

Index	Timeframe	Biological indicators	Physico-chemical indicators	Integrated index (Y/N)?
Trophic Index (TRIX)[1]	Annual	Chl-*a*	DO, DIN, TP	Y
EPA NCA Water Quality Index[2]	Summer-Autumn	Chl-*a*	Water clarity, DO, DIN, DIP	Y
Assessment of Estuarine Trophic Status (ASSETS)[3]	Annual	Chl-*a*, macroalgae, seagrass, epiphytes, HABs	DO, TN, TP, SS	Y
LWQI/TWQI[4]	Annual	Chl-*a*, macroalgae, seagrass	DO, DIN, DIP	Y
OSPAR COMPP[5]	Growing season	Chl-*a*, macroalgae, seagrass, phytoplankton composition	DO, TP, TN, DIN, DIP	Y
Water Framework Directive[6]	Summer	Phytoplankton, chl-*a*, macroalgae, benthic invertebrates, seagrass,	DO, TP, TN, DIN, DIP, water clarity	Y
HELCOM Eutrophication Assessment Tool (HEAT)[7]	Summer	Chl-*a*, primary production, seagrass, benthic invertebrates, HABs, macroalgae	DIN, DIP, TN, TP, DO, C, water clarity	Y
IFREMER[8]	Annual	Chl-*a*, seagrass, macrobenthos, HABs	DO water clarity, SRP, TP, TN, DIN, sediment OM and TN, TP	Y
Statistical Trophic Index (STI)[9]	Seasonal	Chl-*a*, primary production	DIN, DIP	N
Marlborough / NZKS[10]	Seasonal	Chl-*a*, HABs	DIN, DIP, TN, TP, DRSi	N*

1. Vollenweider *et al.* 1998; 2. USEPA 2005, 2008; 3. Bricker *et al.* 1999, 2003; 4. Giordani *et al.* 2009; 5. OSPAR 2002, 2008; 6. Devlin *et al.* 2009; 7. HELCOM 2009; 8. Souchu *et al.* 2000; 9. Ignatiades 2005. 10. NZKS 2012.
* While no integrative measures are explicitly stated in the NZKS consent, development of integrated metrics is a long-term aim, with interim multi-metric consideration of water quality undertaken by an independent review panel.
DIN = dissolved inorganic nitrogen, TN = total nitrogen, DO = dissolved oxygen, DIP = dissolved inorganic phosphorus, TP = total phosphorus, C = carbon, DRSi = dissolved reactive silica, HAB = harmful algal bloom, TSS = total suspended solids.

For the water column, we recommend measuring the full suite of standard indicators listed in Table 5 and Table 6 and trialling various indices such as TRIX, which could be interpreted alongside ES scores. The TRIX approach is being used in water-column monitoring of mussel farms in Nelson bays (Forrest & Knight 2014). Initial results from the application of TRIX show it has potential to be a more stable indicator for assessing changes in the marine environment as opposed to trying to detect trends in a single, highly variable indicator such as dissolved nutrients or chl-*a*. Although not useful for determining trophic state or trends, measurement of physical parameters listed in the tables is required to identify external mechanisms influencing biological and chemical indicators. An example of such a mechanism would be a change to an upwelling-inducing wind that may lead to oceanic enriched nutrient conditions within the Firth of Thames, or the event of an unusually dry or wet period. It is understood that an estuary trophic index (ETI) is being developed for monitoring estuaries that will likely incorporate similar parameters used in the ASSETS index. Within some areas of the CMA, it may be appropriate to collect additional parameters (*e.g.* measurements of macroalgae, seagrass) for calculating an index such as ASSETS, which in turn could provide good linkages with SOE monitoring carried out within estuaries.

4.1.2. Developing standards

Existing trigger points to initiate management actions have been developed for shellfish culture in Wilson Bay, but are not necessarily suitable for SOE monitoring to ensure water quality is maintained. In order to meet the wide policy objective to ‘improve or maintain existing water quality’, standards for the Waikato CMA should include a wider range of tests than are used at present, and also be referenced to sampling at an appropriate number and distribution of reference sites. However, any additional tests should explicitly consider specific aspects of the existing environment that would maintain a level of water quality. This should include both water column and benthic indicators. While benthic indicators do not directly measure water quality, they can provide a more stable indicator over time of benthic changes in response to changes in water quality.

Table 8. Example of typical water column characteristics for different trophic states, as summarised by Smith *et al.* (1999) based on the review by Håkanson (1994). TN= total nitrogen, TP= total phosphorus, chl-*a*, SD= Secchi disc depth (a measure of water clarity).

Trophic state	TN (mg/m^3)	TP (mg/m^3)	Chl-*a* (mg/m^3)	SD (m)
Oligotrophic	< 260	< 10	<1	>6
Mesotrophic	260–350	10–30	1–3	3–6
Eutrophic	350–400	30–40	3–5	1.5–3
Hypertrophic	> 400	>40	>5	<1.5

Ideally the local baseline conditions should be considered in any classification of trophic state, but even with such information available, issues can arise. For example, local guidelines developed for New Zealand and Australia (ANZECC 2000) provide example guideline trigger point concentrations for ammoniacal and total nitrogen (TN) concentrations from Australia (see Appendix 3). It recognised that these limits are not appropriate for New Zealand coastal waters and that these limits are often regularly, and naturally, above ANZECC trigger levels[12].

As described in Section 4.1.1, multi-indicator metrics can be used to arrive at clear assessments of states and trends (*e.g.* ASSETS; Bricker *et al.* 1999, 2003). These integrated approaches can provide a more meaningful measure of changes to managers. Standards around integrated metrics will need to be developed over time once sufficient data is available to establish baselines and the extent of variability. It is likely that standards will need to be based on ranges or bands rather than finite values due to the dynamic nature of the CMA in response to a number of natural drivers.

4.1.3. Monitoring design considerations

There are a number of design considerations relating to the frequency and spatial coverage of sample collection and methodologies that should be taken into account in designing the SOE monitoring programme. A staged approach is recommended whereby the programme focuses initially on the collection of quality data at a low number of sentinel sites, and then expands over time as required and informed by the programme results. Placing resources and effort on a higher sampling frequency rather than spatial extent will enable a robust evaluation of indicators and their usefulness in an SOE monitoring capacity prior to wider application. The long-term monitoring design may include additional sites or a rotation among sites.

The Council should consider collecting high frequency data at sentinel sites in the first one to two years to assess variation and determine the optimal indicators (and integrated metric) to be applied more widely across the CMA. The Waikato CMA within the Hauraki Gulf (that includes the Coromandel and Firth of Thames) presents the greatest opportunity to develop the SOE programme in the short term, with eastern and western regions of the CMA being incorporated as resources and opportunities for integration with consented activities allow.

It is recommended that initial SOE monitoring occur at two locations that coincide with the location of moored sensors (Wai-Q-Tahi in the Firth of Thames and a smaller mooring location). Although focused on a limited number of sites, there will be opportunities to compare more spatially distributed data for specific biological indicators that are sampled more widely (*e.g.* as part of consent monitoring), or those that are collected using methods that account for spatial variation (*e.g.* chl-*a* estimates

[12] An exception is a guideline trigger value for total nitrogen concentrations in south central Australia which are set at a high level of 1000 mg TN/m^3.

based on satellite imagery). If data become available, the NIWA buoy location would also enable additional analyses of spatial variation.

In the first year, a broad suite of water column indicators, such as those listed in Tables 5 and 6, could be monitored at a high frequency using a combination of moored sensors and fortnightly sampling to enable multiple integrated metrics (Table 7) to be calculated and reviewed. Measuring benthic indicators for calculating ES at each of the locations will also enable review of integrated metrics that combine benthic and water column indicators (*e.g.* ASSETS, HEAT). The sampling should also include collecting samples across different depths to assess stratification effects (*e.g.* surface, mid-water, and near bottom). Following a review of results, the appropriate suite of indicators and integrated metric, and the frequency at which they need to be measured, would be selected and then applied more widely across the CMA as required and feasible.

The SOE indicators described in this report focus primarily on the trophic status of the CMA, and align with aquaculture-related effects. There are other indicators that will be important to measure for SOE monitoring, such as status of fisheries or quality of bathing beaches and shellfish harvest areas. In addition, larger-scale processes, such as ocean acidification, need to be monitored to assess long-term environmental changes occurring in response to multiple drivers. Hence, changes in drivers (or pressures) also need to be monitored.

5. INTEGRATING CONSENT AND STATE OF THE ENVIRONMENT MONITORING

A primary aim of this project is to identify opportunities for integrating consent-based monitoring and SOE monitoring conducted in the wider coastal marine area. The rationale lies in the fact that any single consented activity, whether a mussel farm or sewage discharge, contributes toward potential effects occurring in the wider environment. No individual consent holder has the ability to fully address the issue of cumulative effects that are occurring beyond 'reasonable mixing zones' or measureable footprints that can be directly linked to a particular activity or stressor. Nonetheless, the issue of cumulative effects is one that must be addressed to give effect to the Resource Management Act, and the NZ Coastal Policy Statement.

As outlined in the first report (Forrest & Cornelisen 2015), there is ample opportunity to integrate monitoring conducted for managing aquaculture consents with a wider environmental monitoring framework. Significant benefits of integration include efficiencies (cost savings) ranging from coordinated data collection and sample processing to the sharing of reference locations. Ultimately, the datasets generated by integrating data sources will enable more effective management of consented activities within the context of wider, long-term environmental changes. These changes may be occurring in response to cumulative effects, which may include larger-scale processes that lie outside the control of the regional council (*i.e.* climate change, ocean acidification). More rigorous data on climatic trends and the ability to predict productivity will also assist the aquaculture industry in planning stocking levels and harvesting schedules. Even before consents are applied for, access to better SOE-type information can inform the site-selection process for aquaculture and other ventures, thereby facilitating an important component of best management practice.

Integration can occur at various levels. In the simplest case, it can occur among the same type of consented activity. For instance, Coromandel mussel farmers recently applied to extend growing areas around their consented areas and pooled resources by taking a consortium approach to consent-required monitoring, as has been done by WBMFZ Areas A and B. The monitoring was carried out in a single sampling event that involved monitoring at representative farms (rather than each individual farm) and using a set number of reference sites across the area where all the farms were located (rather than each applicant having to monitor a reference location).

As described in this report the effects of different types of aquaculture on the seabed are well understood; the multi-parameter ES approach presents a proven method for establishing monitoring standards that align with the different types of aquaculture. The consortium approach could be expanded over time to cover larger areas of the Waikato CMA such as the Firth of Thames. For instance, while AEEs are a requirement of the RMA, the monitoring that follows at the farm (consent) scale could be nested within the wider monitoring that is occurring within the region, enabling both local-to-regional scale assessments of environmental effects.

5.1. Recommendations for maximising benefits from integration

1. Identify what must be monitored in order to effectively manage a given aquaculture farm; this will vary depending on the type of aquaculture, and where it is occurring. Effective monitoring includes acknowledging that some forms of aquaculture have greater impacts than other forms, and in some cases very little monitoring at the farm-scale may be required (as in the case of seasonal spat-catching).
2. Look for opportunities to minimise redundancy and combine consent-based monitoring efforts for consented farms in close proximity to one another (as in the Coromandel example).
3. Do not require individual consent holders to monitor environmental effects beyond the farm scale (*i.e.* beyond the area of measureable influence – seabed footprint for example) unless there is no baseline or reference information available. *The reason:* effects that occur beyond the immediate area of an individual farm may be partially due to their consented activity but are also influenced by other activities and larger-scale processes (*e.g.* natural variation, climate change). Hence it is very difficult to link cause and effect, and therefore respond to monitoring results. Nevertheless local monitoring may be useless without a frame of reference, so careful consideration of SOE site locations will need to be undertaken to ensure they act as suitable references for consent monitoring.
4. Design a Council-led coastal SOE monitoring programme that is able to assess the potential wider ecosystem effects that may be attributable in part to aquaculture, but within the context of cumulative environmental change. This programme would address the need to assess cumulative effects associated with multiple activities impacting on the CMA.
5. For number 4, parameters (indices) measured should include (but not be limited to) those that are influenced by aquaculture and of direct importance to the environment. Sections 3 and 4 provide recommended indicators, monitoring methodology and steps to establishing standards for a programme based on water-column monitoring. The condition of the seabed as described by the ES scores is a good integrator of effects over time; hence seabed monitoring using methods described in Section 2 should also be included at reference locations within the wider coastal monitoring programme.
6. Once sites and methodologies (parameters and sampling frequencies) are confirmed, establish standardised sampling protocols and data exchange for bringing together data from consent monitoring and wider coastal monitoring into a centralised repository that can be used by industry or WRC for a range of

purposes (industry planning, council SOE monitoring and reporting, contributions to national reporting, shellfish quality monitoring programmes, *etc*.).

In addition to the above recommendations, there are three overarching steps to successful integration.

1. Developing an effective integrated monitoring design.
2. Determining how best to cover the costs associated with carrying out wider environmental monitoring and also integrating and managing datasets held by different users.
3. Governance and oversight.

A conceptual design for an integrated monitoring programme is illustrated in Figure 11. In terms of steps 2 and 3, it is envisioned that the council develops a system for supporting an integrated monitoring programme. This would be supported through a variety of funding sources (industry, regional and central government, sponsorship). The governance aspect of the programme would include participation by industry and other end-users of the data and information generated by the programme. This could be accomplished by establishing a coastal monitoring advisory panel.

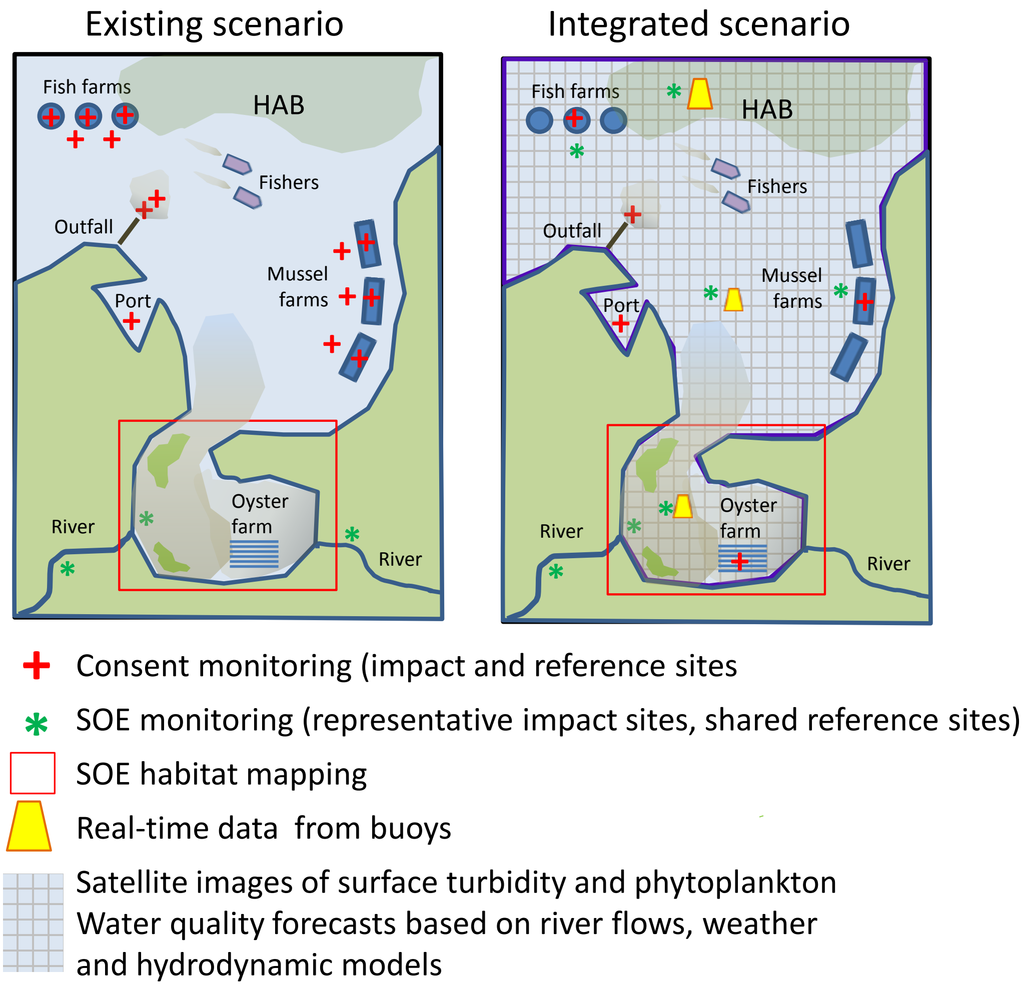

Figure 11. Schematic showing integration of synoptic surveys, real-time & forecasting tools to improve efficiencies, design and implementation of SOE and consent-based monitoring. HAB = Harmful Algal Bloom.

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7. APPENDICES

Appendix 1. Evolution of seabed monitoring for salmon farms in the Marlborough Sounds.

Routine annual monitoring has been conducted at salmon farms in the Sounds since they were first installed (some dating back to the 1980s), as required by the original consent conditions. The monitoring has primarily revolved around measuring near-field seabed effects (see Report 2), and has evolved slightly over last couple of decades, although the fundamental aspects have remained largely unchanged.

In 2014, New Zealand King Salmon Company Ltd (NZ King Salmon) and Marlborough District Council commissioned a review of their environmental quality standards and monitoring protocols, which led to the creation of a best management practice (BMP) document (NZ King Salmon/MDC BMP Part II). This was a collaborative process that involved a representative from Cawthron, MDC, NZ King Salmon, NIWA, community stakeholders (Sounds Advisory Group) and MPI. It resulted in a definitive set of standards (referred to as environmental quality standards or EQS), some of which have been incorporated in the suggested standards below. Other notable changes to the traditional monitoring protocol included:

- Changes to the zone approach: emphasis is now on sampling only in the zone of maximum effect (ZME—usually immediately beneath the pens) and at the outer limit of effect (OLE—formerly the '150 m' or Zone 3-4 boundary), as depicted in Figure A.1. The in-between zone has been discarded for reasons explained in the review document.
- A tiered approach to monitoring has been proposed, with three types of monitoring reflecting three different levels of monitoring intensities. The level of monitoring required is dependent on how the farm has been managed and the previous years' monitoring results.
- The least intensive Level 1 monitoring is based largely on a qualitative assessment, for which clear categorical guidelines have/will be set (*e.g.*Table A.1). This sort of approach is fairly universal and generic, and as such, it is likely to be regionally transferable.

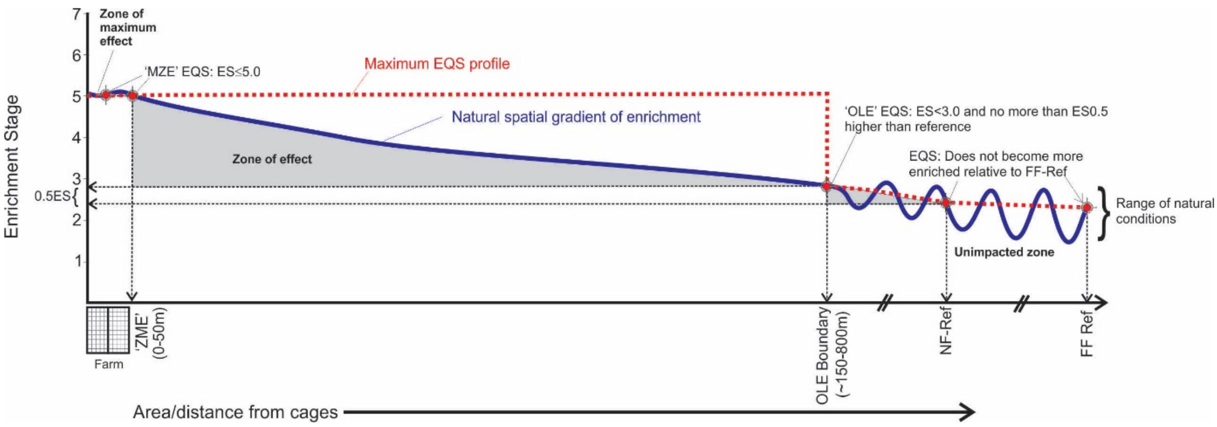

Figure A.1. Stylised depiction of natural spatial enrichment gradient as permitted by the zones concept and associated environmental quality standards (EQS) in terms of overall enrichment stage (ES), along with 'maximum EQS profile' which represents the improbable, but maximum possible EQS profile. ZME = zone of maximum effect, OLE = outer limit of effect, NF-Ref = near-field reference, 'FF-Ref' = far-field reference. Reproduced from: Keeley *et al.* 2014a.

Table A.1. Example of qualitative assessment methods and criteria for Type 1 seabed monitoring (Reproduced from: NZ King Salmon/MDC BMP: Part II).

Qualitative outgassing classifications (suggested acceptable level: ≤ 2)		
Method: Assessment made from observations at surface and from real-time video footage of seabed. Requires repeated physical contact with seabed to assess disturbance, *e.g.* with camera or frame.		**Score**
None	No outgassing observed.	0
Minor	Minor or suspected outgassing (*i.e.*, not obvious).	1
On disturbance	Clear outgassing on disturbance of seabed.	2
Spontaneous	Clear outgassing occurring freely without disturbance. Bubbles obvious on surface around net pens.	3
Qualitative bacterial coverage classifications (suggested acceptable level: ≤ 2)		
Method: Visual assessment from video or drop-camera. Assessment to be made from at least 2 x 1 m^2 of seabed with reference to catalogue of images.		
None-natural	No bacterial matter observed; sediment appear natural/ healthy	0
Trace	Traces of bacterial mat (*Beggiatoa* sp.) within sediments or attached to edges of cobbles or shells.	1
Patchy-minor	Obvious patches of bacterial mat (*Beggiatoa* sp.) on sediment surface, occupying < 50% of surface area.	2
Patchy-major	Obvious patches of bacterial mat (*Beggiatoa* sp.) on sediment surface, occupying > 50% of surface area.	3
Mat	White mat of bacterial mat (*Beggiatoa* sp.) smothering sediment surface (> 90% coverage over area > 1 m^2).	3
None	Bacterial mat absent, but sediments black and highly anaerobic and probably anoxic (redox very low, *e.g.* < -150 mV). Very strong sulphide odours.	3
Macrofauna visual inspection classifications (suggested acceptable level: ≤2)		
Methods: Washed and sieved (0.5 mm mesh) macrofauna sample spread over white tray and inspected by dissecting scope or equivalent by appropriately trained personnel (*i.e.* with necessary taxonomic skills). Qualitative categorical assessments made with reference to catalogue images. Full macrofauna samples are to be archived for six months in case they are needed for full taxonomic analysis.		
Healthy	Healthy array of taxa. Enrichment sensitive organisms such as small bivalves, ophiuroids, echinocardium present.	0
Diverse but enriched (ES3-4)	Seemingly healthy array of taxa, but capitellids, nematodes and/or other opportunistic polychaetes noticeably more abundant.	1
Heavily enriched (ES≈5)	Clearly dominated by capitellids and/or nematodes, with few other taxa. Total abundance very high.	2
Post-peak	Capitellids and/or nematodes present in low to moderate abundances but no other taxa observed.	3
Azoic?	No macrofauna present.	4
Compliance trigger for Type 2 monitoring: • Cumulative score > 6 (out-gassing + bacteria coverage + macrofauna), or • Macrofauna inspection classification > 2		

Appendix 2. Table of Firth of Thames (and inner Hauraki Gulf) datasets containing water column information.

Public/ Private (Custodian/owner)	Location	Dataset & purpose	Date	Variables	Data quantity	Reference
Private (NIWA/ Wilson Bay Group A Consortium)	Five locations at and around Wilson Bay Marine Farming Zone A.	Consent monitoring for Wilsons Bay Marine Farming Zone A.	2001 to 2014	Extensive water column variable monitoring of: chlorophyll-a, dissolved nitrogen (DN),organic solids, total phytoplankton biomass, diatom biomass, dinoflagellate biomass, phytoflagellate biomass, ciliate biomass, larval copepods, juvenile/adult copepods, temperature, water transparency.	1000+ samples for most variables (bi-monthly sampling at five locations over > 10-years).	Stenton-Dozey & Zeldis (2012) and earlier monitoring reports
Public (Cawthron/WRC)	Five locations Spread throughout the Firth.	Marine management model calibration data.	24 May to 10 July 2012.	Currents, salinity, temperature	Fine-scale (< 30 min) measurements over six weeks.	Dunmore *et al.* (2012a)
Private (NIWA)	Single mooring location in the Outer Firth of Thames/ Hauraki Gulf (36 45.6'S, 175 18.0'E) – most relevant to Coromandel Marine Farming Zone.	Proposed marine farming zone monitoring—long-term water column physical, dissolved oxygen and nutrient data.	2005 to present	Water currents, temperature, salinity, oxygen, light attenuation, chlorophyll-*a*, full suite of macro-nutrient data including available nitrogen, phosphorus and silicates.	High temporal resolution (< 30 min) for physical and chlorophyll data; approximately monthly data or longer for nutrient data.	Zeldis *et al.* (2010)
Public (NIWA and Waikato University/ Public access)	Western Firth of Thames.	Mussel farm nutrient flux study.	2006	Physical measurements, primary production, oxygen and nitrogen flux data.		Giles (2006)[13]
Public (Cawthron /Sealords; Tom Hollings)	Variety of Coromandel farms.	Mussel farm extension assessments.	2011	Depth, 3D current measurements (ADP).		Part of Taylor *et al.* (2012)

[13] http://researchcommons.waikato.ac.nz/bitstream/handle/10289/2548/thesis.pdf?sequence=2

Public/ Private (Custodian/owner)	Location	Dataset & purpose	Date	Variables	Data quantity	Reference
Public (NASA)	Entire surface WRC region, including Firth of Thames, east and west coasts.	Moderate resolution imaging spectroradiometer (MODIS) data from aqua and terra satellites: surface global ocean optical reflectance measurements.	2002 to present	Sea surface temperature, light attenuation, chl-*a* concentration. Additional local validation of chl-*a* required for improved confidence.	Twice daily images (one Aqua and one Terra image) across 18 spectral wavelengths. Potentially greater than 6,000 surface measurements are possible for anywhere in the WRC region.	Jones *et al.* (2013)
Public (WRC)	Firth of Thames and Hauraki Gulf throughout the water column at >100,000 locations.	Hauraki Gulf marine management model; physical data for a two-year period and tools to allow prediction of bulk transport, mixing and cumulative effects.	2010 to 2011	Temperature, currents, mixing and salinity. Note that salinity accuracy not known due to collected data issues identified.	Two-year hindcast of 10 minute data available.	Beamsley & Knight (2013)
Private Cawthron/Wilson Bay Group A Consortium	Wilson Bay Marine Farming Zone.	Data collection of harmful algae undertaken to ensure safe harvesting of mussels.	2001 to 2014 Mainly collected during the harvesting season (*e.g.* October to April).	Harmful algal cell count data.	Periodic during the harvesting season, or as required.	

Public/ Private (Custodian/owner)	**Location**	**Dataset & purpose**	**Date**	**Variables**	**Data quantity**	**Reference**
Public	Waikato CMA, particularly Coromandel and West Coast areas.	State of the environment Waikato Coastal Water Quality Monitoring.	1973 to 2000 Mainly Summer Sampling	General coastal water quality parameters, including: temperature, salinity/conductivity, turbidity, absorbance, pH, biochemical oxygen demand, dissolved oxygen, total phosphorus, dissolved reactive phosphorus, nitrate, ammonium, nitrate-nitrite nitrogen, total Kjeldahl nitrogen, sulphate, faecal coliforms, faecal streptococci, total coliforms, *Escherichia coli*, enterococci bacteria, heterotrophic plate counts, turbidity, suspended solids, salinity and temperature.	Up to 1500 results are available for a number of variables. Over 90 sites have been sampled. Most are located in the Coromandel and West Coast areas, and most sampling has occurred during the summer.	Environment Waikato (EW) DOCS#559844. http://waikatocoastaldatabase.org.nz/DataSet/Detail/69
Results publically available in report as referenced.	Southern Firth of Thames.	Environment Waikato Funded report to forecast possible phytoplankton Responses to elevated riverine nitrogen delivery into the Firth of Thames.	Defined periods; including September 1999, March 2000 and May 2003	Chl-*a*, plankton group biomass, nutrient and physical variables	Modelling results for three defined periods at all locations in the Firth of Thames available.	Broekhuizen & Zeldis (2006) http://waikatocoastaldatabase.org.nz/DataSet/Detail/222

Public/ Private (Custodian/owner)	Location	Dataset & purpose	Date	Variables	Data quantity	Reference
Results publically available in report as referenced.	Firth of Thames.	Environment Waikato funded biological modelling to assess ecological sustainability for the Firth of Thames shellfish aquaculture.	?	Chl-*a*, phytoplankton abundance, snapper eggs, nutrient and physical variables.	Modelling results for three defined periods at all locations in the Firth of Thames available.	Broekhuizen *et al.* (2005) http://waikatocoastaldatabase.org.nz/DataSet/Detail/219
Public	Whaingaroa (Raglan) and the southern Firth of Thames.	Waikato Regional Estuary Monitoring – sediment/benthic focussed, but with turbidity measurements also taken for the water column.	2001-present	Turbidity, grain size, sedimentation rates, chl-*a*, phaeophytin, sediment total organic carbon and total nitrogen.	3-monthly data available for most sampled estuary properties from 2001.	Several reports published from 2002 to 2010 under the 'Regional Estuary Monitoring Programme'. www.waikatoregion.govt.nz/REMP

Appendix 3. Stressor and toxicant guidelines for the protection of saltwater aquaculture species. Adapted from ANZECC (2000).

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Stressor	Guideline (µg/L)	Reference
Alkalinity	> 20	1
Carbon dioxide	< 15	
Colour and appearance of water	30–40 (Pt-Co units)	6
Dissolved oxygen	> 5	1
Gas supersaturation	< 100%	8
pH	6.0-9.0	
Suspended solids	< 10 (< 75 Brackish)	
Temperature	< 2.0 °C change over 1 hour	9
Toxicants		
Aluminium	< 10	1
Ammonia (un-ionised)	< 100	
Arsenic	< 30	1,2
Cadmium (varies with hardness)	< 0.5–5	1
Chlorine	< 3	1
Chromium	< 20	
Copper (varies with hardness)	< 5	3
Cyanide	< 5	1
Hydrogen sulfide	< 2	
Iron <10	<10	1
Lead (varies with hardness)	< 1–7	4
Manganese	< 10	1,5
Mercury	< 1	
Nickel	< 100	1
Nitrate (NO3-)	< 100 000	3,7
Nitrite (NO2)	< 100	1,7
Phosphates	< 50	
Selenium	< 10	1
Silver	< 3	1
Tributyltin (TBT)	< 0.011	
Total available nitrogen (TAN)	< 1000	1
Vanadium	< 100	1
Zinc	< 5	1
Polychlorinated biphenyls (PCBs)	< 2	1
Chlordane	< 0.004	10
Endosulfan	< 0.001	10
Lindane	< 0.04	10
Paraquat	< 0.01	

1. Meade (1989); 2. DWAF (1996); 3. Pillay (1990); 4. Tebbutt (1972); 5. Zweig *et al.* (1999); 6. pers. comm O'Connor; 7. Coche (1981); 8. Lawson (1995); 9. ANZECC (1992); 10. Lannan *et al.* (1986); Others are based on professional judgements of the ANZECC (2000) project team.